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Reducing Aircraft COMBAT Casualties

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On the cover: A US Army (USA) AH-64 Apache helicopter that crashed during landing at Tactical Assembly Area SHELL in Central Iraq. *Photograph by SGT Igor Paustovski, USA.*

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News Notes

by Dennis Lindell

Instrumentation Round Table

Dr. Torger Anderson organized and led the fourth annual Instrumentation Round Table on 15 September 2008. The continuing objective of this meeting is to bring together Service range test representatives in order to identify ballistic range instrumentation capabilities, needs, and issues and to discuss potential avenues for range instrumentation improvement. This year, particular emphasis was placed on crew casualty test and evaluation.

The discussions centered on casualty evaluation expertise provided by Mr. Pat Gillich and Ms. Nikki Brockhoff of US Army Research Lab, Survivability/Lethality Analysis Directorate (ARL/SLAD) and established some priorities and test methods for Live Fire Tests that could evaluate casualty mechanisms. Their presentation described the capability and application of the Army's Operational Requirement-based Casualty Assessment (ORCA) model, and its various analysis modules, to estimate several damage effects on the crew and passengers, including blast overpressure, fragments, toxic gases, and thermal effects. Although test requirements are far from established, this discussion formed a starting point for the Casualty Assessment Workshop that was held in January 2009 at Aberdeen.

The 47 attendees (from all three Services) seemed very positive about this meeting, stating that it provided opportunities to discuss their measurement issues and make useful connections. They encouraged planning similar discussions at future JASPO meetings to review and evaluate other instrumentation areas.

Wireless Fire Detection and Reporting System for Aircraft

The effectiveness of fire extinguishing systems relies on its ability to rapidly and reliably detect fires, particularly in areas where the crew cannot confirm the presence of a fire emergency. Previous on-board fire detector systems were prone to giving false alarms, costly, and heavy due to the weight of running wiring to all the protected areas on the aircraft. The combination of these problems often caused aircraft designers to remove the fire detection and suppression equipment. The Air Force's 780th Test Squadron at Wright-Patterson AFB is in the process of remedying this matter. Phase I Small Business Innovative Research contracts were issued to several independent teams for development of a wireless, rapid, low-cost, lightweight fire detection system. Intended for application as a combat kit, the future fire detector must be reliable and easy to install. Those teams demonstrating the most promising approach will be invited to participate in a Phase II award for advanced development of the fire detection/reporting hardware to help maintain aircraft safety and survivability.

JASPO 2009 ACS Short Course

The Joint Aircraft Survivability Program Office will host its 2009 annual Aircraft Combat Survivability short course at the Naval Postgraduate School (NPS) 28 April–1 May 2009. The lead instructors will be Professor Christopher Adams, Associate Dean for the School of Engineering at NPS and Dr. Mark Couch from the Institute for Defense Analyses. Several invited subject matter experts from government and industry will provide additional instruction.

This 4-day course is intended for engineers and program managers who have less than five years working in the survivability discipline. The course will be similar to last year's in format following the methodology outlined in the 2nd Edition of Dr. Ball's textbook, *The Fundamentals of Aircraft Combat Survivability Analysis and Design,* published by the American Institute for Aeronautics and Astronautics. The course will cover a broad spectrum of topics including—

- Introduction to aircraft survivability
- Historical and current survivability combat loss data
- Mission and campaign survivability analysis
- Iraq & Afghanistan Threat Intel brief
- Threats and threat effects
- IR, Radar, and EW fundamentals
- Current Susceptibility Reduction technology
- Current Vulnerability Reduction technology
- Overview of modeling and simulations for survivability
- Methodologies for conducting a survivability analysis
- Joint Live Fire and Live Fire Test programs
- Personnel casualties and safety
- Current initiatives in the survivability community

Sections of this course will be classified, and prospective students must be US citizens possessing a SECRET clearance. Students will receive a copy of Dr. Ball's textbook at the beginning of the course, and it is recommended that students bring a calculator capable of performing exponential calculations as the instructors lead the students through some practice problems designed to enhance understanding of the material. To foster closer working relationships, there will be a social and dinner held at the *Taste of Monterey on Cannery Row* as part of the course on Wednesday, 29 April. Guests of attendees are also invited to attend the dinner for an additional fee of $50/person.

Registration information is available at *http://www.bahdayton.com/jasp2009* or contact Mr. Paul Jeng at SURVIAC. For further information about the course, contact lead instructor is Prof Chris Adams, or Dr. Couch, Cost is $750 for US government/military and $1,000 for industry.

A block of rooms has been reserved at the Hyatt Regency Monterey, conveniently located by the 10th Street Gate to NPS, (*http://monterey.hyatt.com* or 831/372-1234) located at 1 Old Golf Course Road, Monterey. Additionally, a block of rooms is available to Gov/

Industry for $133/nt at the Hilton Garden Inn (*www.monterey.stayhgi.com* or 831/373-6141) located at 1000 Aguajito Road, Monterey, CA. Attendees are responsible for making their own room reservations.

New NDIA CSD Chairman

The National Defense Industrial Association's (NDIA) Combat Survivability Division (CSD) has a new chairman. BG Stephen D. Mundt, USA (ret) was selected as the Chairman by the CSD Executive Board on 27 August 2008 and directed the activities of the CSD and the NDIA Aircraft Survivability Symposium in Monterey, CA on 4–7 November 2008. General Mundt has a long and impressive career in the Aviation side of the Army with his last assignment as the Director of Army Aviation in Headquarters, Department of the Army. In that position he was responsible for the coordination of Army Aviation Transformation, Modernization, and support to ongoing Combat Operations. He previously had been the Assistant Division Commander of the 1st Infantry Division Combat Team deployed to North Central Iraq conducting simultaneous combat and stability operations in support of Operation Iraqi Freedom (OIF) 2. General Mundt is very knowledgeable about combat survivability and was a staunch advocate for upgrading Aircraft Survivability Equipment (ASE) on Army aircraft—an area that had been neglected for years. Gen Mundt's efforts contributed significantly to gaining approval for and finally implementing a $3.5B program that provided state-of-the-art ASE systems for Army aircrews operating in OEF/OIF. These efforts have saved valuable aircraft assets and the lives of numerous aircrew members. He knows current ASE systems firsthand and strongly supports aircraft survivability as a total system incorporating electronic countermeasures, suppression, vulnerability reduction, and pilot situational awareness. The JASP welcomes General Mundt to the CSD and looks forward to working with him and NDIA to protect and enhance the effectiveness of our soldiers, sailors, airmen and marines.


BG Stephen D. Mundt

Joe Manchor

With the planned retirement of Al Wearner next year, Joe Manchor has replaced Al as the Navy Co-Chair of the Joint Aircraft Survivability Program's (JASP) Vulnerability Reduction Subgroup and the Navy Joint Live Fire Deputy Test Director. Joe is a long time member of the JASP, having served as the Chairman of the Fuel Systems Committee for a number of years. Joe has also been the lead on a number of important Navy programs such as the V-22 LFT&E Program. Joe's military experience includes serving as a P-3 Naval Flight Officer making him even more knowledgeable about survivability than most people. Welcome to your new responsibilities, Joe.


Joe Manchor

The Aircraft Combat Survivability Self Study Program (SSSP)

SURVIAC is pleased to announce the availability of the Aircraft Combat Survivability Self Study Program (SSSP). The SSSP has been funded by the Joint Aircraft Survivability Program (JASP) and was developed by Distinguished Professor Emeritus Robert E. Ball. Nearly all of the material in the program has been taken from the Prologue and Chapter 1 of the textbook "The Fundamentals of Aircraft Combat Survivability Analysis and Design, Second Edition," written by Dr. Ball and published by the American Institute of Aeronautics and Astronautics (AIAA) in late 2003.

The purpose of the program is to provide a quick, easy, and effective way for users to learn about the fundamentals of the aircraft combat survivability discipline. The program currently consists of the module, "Introduction to the Aircraft Survivability Discipline" but additional modules may be added in the future. The sections available under this module are "Overview of the Fundamentals," "Historical Perspective of Survivability," "US Military Survivability Policy, Instructions, Programs and Organizations," "Designing for Survivability," "Survivability Modeling and Simulation," "Testing for Survivability," "Conclusions and Points to Remember."

Program Features

An opening video plays when the program is first launched. After the video, the introduction splash card appears. From this card you can access the instructions on how to use the program and the credits for the program, begin your personalized study, continue your study, and replay the video. Some of the program features are the ability to highlight text, watch videos, save your study data, add your own notes, solve survivability problems, monitor your progress through a report card, and email questions to Dr. Ball. The user can save, quit, and return to the program at any time, starting where they previously stopped. All user notes, highlighted text, finished subsections, and the report card are saved when the user saves the program. Additional information on the SSSP and how to use it can be found on Prof. Ball's Aircraft Combat Survivability Education website, *http://www.aircraft-survivability.com/Pages/Education_Frame.html.*

Obtaining the PROGRAM

The SSSP can be obtained from SURVIAC at *http://www.bahdayton.com/surviac/survivabilityeducation.htm*. Versions of the program are available for both Windows and Apple computers, and both versions require QuickTime. You can download any version directly from the website, and you may also request a CD containing all of the versions.

Although the textbook is not required when using this program, you may find it helpful to have a copy available. A copy of the textbook can be obtained from AIAA at *http://www.aiaa.org/content.cfm?pageid=360&id=1008*.

US Government civilian and military employees can obtain a copy free of charge from SURVIAC.

JCAT Corner by CAPT Kenneth Branham, USN

2009 Threat Weapons and Effects Training Seminar

The Army component of the Joint Combat Assessment Team (JCAT) is the Army Shoot Down Assessment Team, more commonly known as ASDAT. They will be hosting this year's Threat Weapons and Effects (TWE) Training Seminar at Hurlburt Field/Eglin AFB, FL 21–23 April 2009. The seminar's title is *ASIA RISING* and will focus on the United States Pacific Command (PACOM) area of responsibility. The seminar is held annually and is a collaborative effort between the JCAT [sponsored by the Joint Aircraft Survivability Program Office (JASP), Aeronautical Systems Center (ASC), Naval Air Systems Command (NAVAIR), and the Army Research Laboratory], Defense Intelligence Agency (DIA) (with support from the Missile and Space Intelligence Center), and other agencies. Last year's TWE was a huge success and standing room only for a few unfortunate guests—there were 249 registered conference attendees for an auditorium seating 200 personnel.

The goal of the seminar is to provide not only intellectual stimulus but also practical, hands-on training on the lethality of threat air defense systems and the damage they can inflict on friendly aircraft. Information is drawn from threat exploitation, live fire testing, and combat experience to provide a complete picture on threat lethality. A hands–on experience is provided through the use of threat munitions/missiles, test articles, damaged aircraft hardware, and videos from various test activities and actual combat. The Missile and Space Intelligence Center (MSIC) is slated to provide their Man Portable Air Defense Systems (MANPADS) education trailer for more hands on exposure. Live fire demonstrations scheduled include Stinger missiles. ASDAT is also working with the Air Force Special Operations Command DIT team to provide a small arms and anti-terrorist demonstration.

Experienced instructors will provide current, relevant information briefs on threat system upgrades, proliferation and lethality for countries of interest. They are typically very informative with detailed analysis supported by the Missile and Space Intelligence Center (MISC) and National Ground Intelligence Center (NGIC) of the Defense Intelligence Agency. Other briefs usually include JASP & JLF-Air overviews, JCAT summary and incident briefs, and ASDAT summary briefs, as well as specific country Intel briefs.

The seminar is classified secret/NOFORN and is open to operations, intelligence, tactics, logistics, as well as engineering and analysis personnel. Be watching for additional announcements for an outstanding opportunity for some in depth threat weapons training and professional development.

JCAT News…From the Front

The Joint Combat Assessment Team (JCAT) forward continues to support the warfighter in both theaters of the war. CDR Craig Black, USN, arrived in Al Asad in June 2008 and served as the OIC until November 2008 when he redeployed to Afghanistan to support Operation Enduring Freedom (OEF). During his tour in Al Asad he was responsible for conducting assessments and training Army and Marine Corps aviation units. As the OIC in OEF, he has the arduous task of establishing the JCAT footprint in Afghanistan. We haven't heard much from Craig since heading for the high mountains, but know he is continuing the stellar performance he demonstrated while in Iraq. CDR Black is scheduled to redeploy back to CONUS during the first quarter of calendar year 2009.

CDR Cliff Burnette, USN, arrived in Baghdad July 2008, serving as the JCAT LNO and assumed Surface-to-Air-FIRE Manager (SAFIRE) duties in October. His duties as the SAFIRE Manager, which includes the collection, organizing and reporting of SAFIRE information throughout the entire theater, is critical to combatant commanders and analysis personnel alike. He provides Multi-National Corps-Iraq (MNC-I) and battlefield commanders key tools to conduct aircraft battle damage assessments/investigations, forensic

Continued on page 31

LTJG Kiefer and CW03 Mesa Assessing Damage to a CH-53 at Al Asad Air Base

LTJG Kiefer as He Arrives in Theater Aboard a USAF C-17

Reducing Aircraft Combat Casualties

by Dr. Joel Williamsen

Historically, aircraft combat survivability design metrics and evaluations have focused on what happens to the aircraft, with only limited consideration given to casualties generated during combat-induced aircraft damage or loss. Recognizing this, on 6 May the National Defense Industrial Association's (NDIA) Combat Survivability Division held its annual Aircraft Survivability Workshop at IDA on "Reducing Aircraft Combat Casualties," developing the topic in concert with the Director of Operational Testing and Evaluation (DOT&E) as an outgrowth from last year's NDIA workshop on aircraft vulnerability reduction, as well as from studies of recent air combat casualty data from Operations Enduring Freedom and Iraqi Freedom.

The objectives of this workshop were to identify critical needs (technologies, policies, analysis methods, and/or procedures) for understanding and reducing aircrew/passenger casualties during combat, and to explore advantages of better integrating combat survivability and safety communities to achieve this. Eighty-two participants from 28 government and industry organizations—including warfighters, aircraft designers and fabricators, program managers, and survivability and safety specialists—came together to study combat data, share information, and brainstorm ideas for ongoing or upcoming programs that could benefit aircraft crew and passenger combat survivability. The findings and recommendations from the workshop will be presented this summer to Mr. John Young, Under Secretary of Defense for Acquisition, Technology and Logistics, with copies to other Pentagon leaders. Copies of the report may be obtained from Mereidieth Geary at NDIA.

Summary of Findings

Combat and Mishap Casualty Data

Recent combat data indicate that—

- ➤ Most of the occupant injuries and fatalities appear to have occurred as a subsequent, indirect result of the crash—not as a result of direct threat effects wounding the occupants.
- ➤ A high percentage of helicopter shoot-down events are survivable. Even helicopter shoot-downs by man-portable air-defense systems (MANPADS) missiles are sometimes survivable. Aircraft having design features such as fire protection, energy absorbing seats, and the ability to maintain sufficient internal space for the crew/passengers after a crash from being injured by collapsing massive overhead components (*e.g.*, rotors and gearboxes) can make a significant difference in crash survival rates.
- ➤ Passengers make up a majority of aircraft occupant losses in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF).
- ➤ Combat-related shoot-down assessments do not contain the same type of information normally developed during aircraft mishap/accident investigations. Data regarding the nature of the casualties (type of injury, condition of the aircraft at the time of crash, *etc*.) and those who are uninjured (numbers, locations, protective equipment, *etc*.) are not currently being gathered in theater, and are not available for dissemination to designers.

Injury data related to mishaps can be used to inform designers, but are not always readily available for use, or in a form that could guide the development of requirements. A study summarizing injuries related to DoD helicopter mishaps from 1985 to 2005 has recently been presented by Col Peter Mapes from Deputy Under Secretary of Defense Readiness/ Readiness Programming and Assessment [DUSD(R)/RP&A], but it does not include combat-related crash casualty data. It is possible that combat damage-induced crashes have differing and more debilitating on-board conditions prior to the crash than in non-combat related mishaps. These conditions might include an increased incident of fire, explosions/reactions of combustible materials and toxic fumes onboard the aircraft, more severe loss of control and power, and the presence of structural damage that reduces the aircraft's inherent crashworthiness. By closely analyzing the data retrieved from the combat-related crashes and establishing design requirements based on these data, some damage attenuating technologies such as fire extinguishers and more damage tolerant (soft) landing design features might more readily "buy their way" onto an aircraft.

Though all Services are committed to improving aircraft occupant survivability through (combat-related) vulnerability reduction and (peacetime) crash safety/ egress technologies, communication between these two related technical communities varies greatly from Service to Service. The Army rotary wing community has achieved the closest communication between the crash safety and combat-related vulnerability reduction personnel, since these organizations are co-located in the same organization at the branch level. In general, more communication between the safety and vulnerability reduction communities is needed, as is coordination of crashworthiness efforts across Services and civilian aviation agencies.

Needed: Design Focus on Casualties

Rotary wing aircraft have significantly increased their gross weight since the original airframes were tested for crashworthiness, and even then, some of the aircraft did not pass the existing standards. New standards are being developed that will include the effects of varying the type of terrain at impact (*i.e.*, grass, sand, and water); however, these standards are being developed without the benefit of combat-related crash and casualty data, as it is not available.

Aircraft survivability evaluations and vulnerability testing have historically focused on the loss of the aircraft or its mission, and not on occupant casualties. Although many of the steps taken to save the aircraft can also save the occupants, attention also should be paid to saving the occupants even when the aircraft is lost. Likewise, design features that are optimized to reduce aircraft losses (within constraints on cost, weight, and effectiveness) might not be optimal for reducing occupant casualties. For example, H-60 accident investigations showed that loss of power was the most frequent mechanical cause of Class A incidents (in which the resulting total cost of property damage is $1,000,000 or more; an aircraft is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability), but that loss of control caused the greatest total number of casualties, because the crashes were worse.

New design improvements needed for reducing casualties will require the extension of current analysis methods or models and test procedures to explicitly address occupant casualties. In response to this need, in November 2007 DOT&E issued a directive to expand survivability assessments to include evaluation of casualties due to both direct and indirect damage effects (indirect effects including instances where the occupant is not directly injured by the threat but suffers subsequent injuries from bail out/ejections, secondary damage effects, forced landings, or crash impacts).

Consider Direct and Indirect Effects on Passengers and Crew

To fully address casualties, both analysis and test damage assessments would have to be expanded in scope to consider both direct and indirect effects. Current aircraft vulnerability analysis models are capable of estimating crew casualties from direct ballistic impacts, but casualties are not typically reported as outputs. The models do not address casualties from indirect effects such as crashes. Moreover, post-test damage assessments do not report any inferences regarding personnel casualties. Enhancements to vulnerability models will be required to address occupant casualties from indirect effects, accounting for safe escape from a damaged aircraft in flight, crash survival, and safe escape from a downed aircraft. Post-test damage assessments would need to include inferences as to what might have happened to the occupants, in order to make comparisons with model predicted outcomes to validate the models or analysis methods.

The new Joint Cargo Aircraft program will include a crew and passenger casualty (CAP-C) evaluation that considers a mix of inputs from probabilistic vulnerability models, threat vignettes, landing scenarios, and egress exercises to produce an evaluation of crew casualties from the point of threat encounter all the way to a safe landing. Such a mixed quantitative/qualitative evaluation strategy appears to be a viable alternative until more sophisticated models are developed.

Focus on Casualties in Requirements Development and Evaluation

As indicated earlier, DOT&E has already signaled an increased emphasis on casualty evaluation and reduction in a letter to the Joint Aircraft Survivability Program (JASP) stating that "assessment of aircraft crew and passenger casualties to the point of safe return or egress is an important element of the Congressionally mandated Live Fire Test and Evaluation, including evaluation of personnel casualties due to combat-related in-flight escape and crash events. This necessitates acquisition decision makers, system designers and requirements writers to make quantifiable casualty predictions to evaluate applicable technologies and procedures that reduce crew and passenger casualty risk after initial aircraft hits." The resulting methodology could be particularly useful in establishing and evaluating related Force Protection requirements and Key Performance Parameters (KPPs), as well as in design trade studies.

Until now, JASP survivability technology development programs have focused on susceptibility and vulnerability of the aircraft, and have not considered egress, ditching, and crashworthiness as elements of aircraft survivability. Consequently, an increase in resources will likely be required in order to support this expanded scope and reduce air combat casualties.

Recommendations

The general recommendation from the workshop is for DoD to support the aircraft survivability and safety communities in gathering, sharing, and distributing data on combat-related aircraft crew and passenger casualties; extend current aircraft survivability evaluations to include explicit estimates of occupant combat casualties; require that post-test damage assessments take into account any inferences that can be drawn regarding personnel casualties; and encourage the use of casualty-based metrics as a basis for the development of aircraft Force Protection requirements.

Five specific recommendations emerged from the workshop. DoD should—

1. Encourage design engineers and evaluators to consider crashworthiness, egress, and other casualty reducing features during acquisition of new systems, and improve occupant survivability from combat-related crashes.
2. Develop a process to acquire and integrate combat-related casualty data with mishap casualty data, and enable release of these data to the aircraft design communities to improve crew and passenger survivability. Questions to be answered include—
   - Were casualties induced by direct fire, combustibles' reactions or crashes?
   - What system failures caused each crash?
   - Do combat threat-induced crashes produce more post-crash fatalities/injuries than non-combat causes for crashes?
   - What safety features (seats, egress, fire suppression) need to be improved, especially considering threat effects?
   - What aircraft features contributed to the casualties (loss of cabin space, pilot impact with control stick, inability of seats to attenuate vertical Gs) and what aircraft features prevented casualties (crashworthy seats, crashworthy landing gear)?
3. Develop evaluation metrics, techniques and models to determine crew and passenger casualty levels for aircraft; pursue the establishment of casualty-

related aircraft Force Protection requirements using these metrics; and evaluate legacy aircraft performance using these metrics to reduce casualties. Specific actions should include—

- Include crew casualty evaluation in the system Test and Evaluation Master Plan (TEMP), incorporating safe landing and egress considerations.
- In Live Fire test plans, include explicit requirements and test issues for assessment of crew and passenger survivability (including effects on safe landing or egress) as part of the post-test damage assessment.
- Once a verifiable casualty-related methodology is developed, pursue the development of Force Protection KPPs that relate directly to crew and passenger casualties
- Develop computer models that determine fixed and rotary wing crash conditions given damage, considering that there may different approaches between these aircraft.
- Models should—
  - Support the requirements definition process
  - Support the design and trade study processes
  - Maintain relevance to the acquisition decision process.

4. Establish routine opportunities for exchange and/or joint development of technology, design tools and evaluation methodologies within the aircraft combat survivability and the aircraft non-combat operational safety communities. Areas of emphasis should include—
   - Simulated combat damage and secondary effects (smoke, impediments, *etc.*) in aircraft egress safety evaluations.
   - Coordination with other organizations that might have an interest in this area, such as FAA, NASA, and the auto industry.
     - Survey available crash test facilities, manikins, technologies, *etc.*
     - Survey injury categories from peacetime mishaps and DoD ground vehicles in formulating casualty metrics.
5. Support the expanded role of the Joint Aircraft Survivability Program as the Tri-Service coordinator for above recommendations. ■

The JASPO Casualty Assessment Initiative

by Dr. Torger J. Anderson, Dr. Joel Williamsen, Peggy Wagner, Philip Radlowski, Patrick Gillich, John Manion, and Barry Vincent

At the request of Mr. Richard Sayre, Director of Live Fire Test and Evaluation, the Joint Aircraft Survivability Program Office (JASPO) has begun a project to incorporate crew and passenger casualty assessments into aircraft survivability evaluations. The initiative is being executed through JASP project M-08-09 Aircraft Combat Occupant Casualty project from FY08–FY11, and its ultimate goal is to include aircraft occupant casualty reduction as a vulnerability design consideration in the acquisition process.

In his letter, the Live Fire Director encouraged JASP to—

- ➤ Conduct background investigations into the causes and types of crew and passenger casualties, using combat and safety-related incident data.
- ➤ Assess potential for crew and passenger casualties in Joint Live Fire test and evaluations, which may include specialized crash and/or egress-related testing.
- ➤ Develop/expand tools that predict probability/number of casualties, crash conditions at landing, and crash effects on crew and passengers, including failed egress.
- ➤ Identify and evaluate new casualty reduction features for aircraft considering crashes, hard landings, and ditching at sea.
- ➤ Coordinate with other organizations within and outside the DoD (*e.g.*, AT&L, Safety Centers, DHS, FAA, NASA) to accomplish these goals.

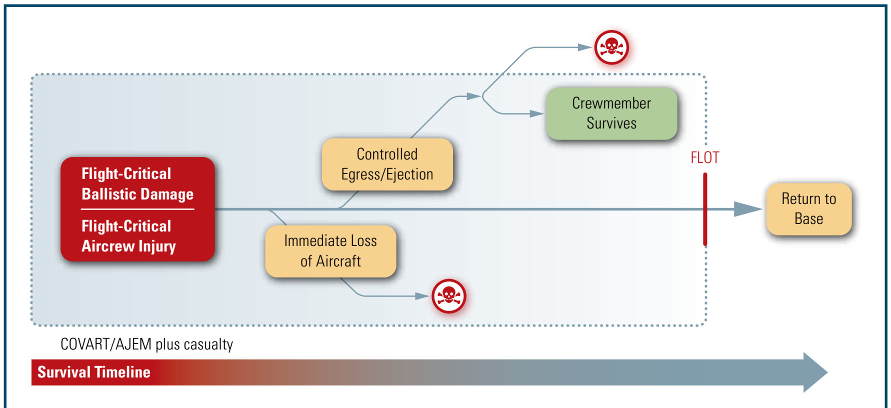

Figure 1 Simplified Description of a Survivability Assessment with the Current Methodology

The current aircraft survivability assessment process must be extended in order to accomplish these objectives. Figure 1 diagrams the basics of the current aircraft survivability assessment methodologies used by all the Services. Since the analysis is concerned with aircraft survivability, casualty considerations relate only to "flight-critical" crewmembers of the aircraft. Also, the current analysis of flight-critical crewmembers only extends to when they are forced to leave the aircraft through emergency egress or ejection, so even the casualty assessments of these select individuals is incomplete. Finally, most aircraft acquisition programs historically have only assessed the survivability until the aircraft leaves the combat area (*e.g.*, to the Forward Line of Threat, or FLOT), ignoring delayed effects of combat damage. These might include damage to components or systems that are not critical for normal flight, but which will be required for the return to base or for landing. Damage to these systems could subsequently lead to casualties or loss of aircraft later in the mission.

Expanding the current methodology to assess potential casualties would require additional considerations as shown in Figure 2. First, the likelihood of injuries resulting from the ballistic encounter must be expanded to include the crew, both critical and non-critical, and to any additional passengers. Adding the latter group will be especially important for aircraft expected to carry passengers or troops into combat—both cargo planes and large helicopters.

Secondly, the assessment needs to consider survival of individuals upon egressing the aircraft. In a tactical jet, for example, a crewmember may eject, but there is some risk for the proper operation of the ejection seat and parachute, especially since ballistic damage may be involved. Even if the ejection sequence is completed successfully, environmental variables add risk to surviving the event. The crew may not be able to choose when to eject, perhaps even departing when the aircraft is out of the ejection system envelope. Similarly, a desirable geographic environment may not necessarily be available and the crew may be forced to eject over mountainous or wooded terrain or over cold water. Each of these considerations adds significant risk to survival. It may be argued that these risks are unrelated to the crew casualty attributes of the aircraft under evaluation, but, in fact, their consideration adds realistic

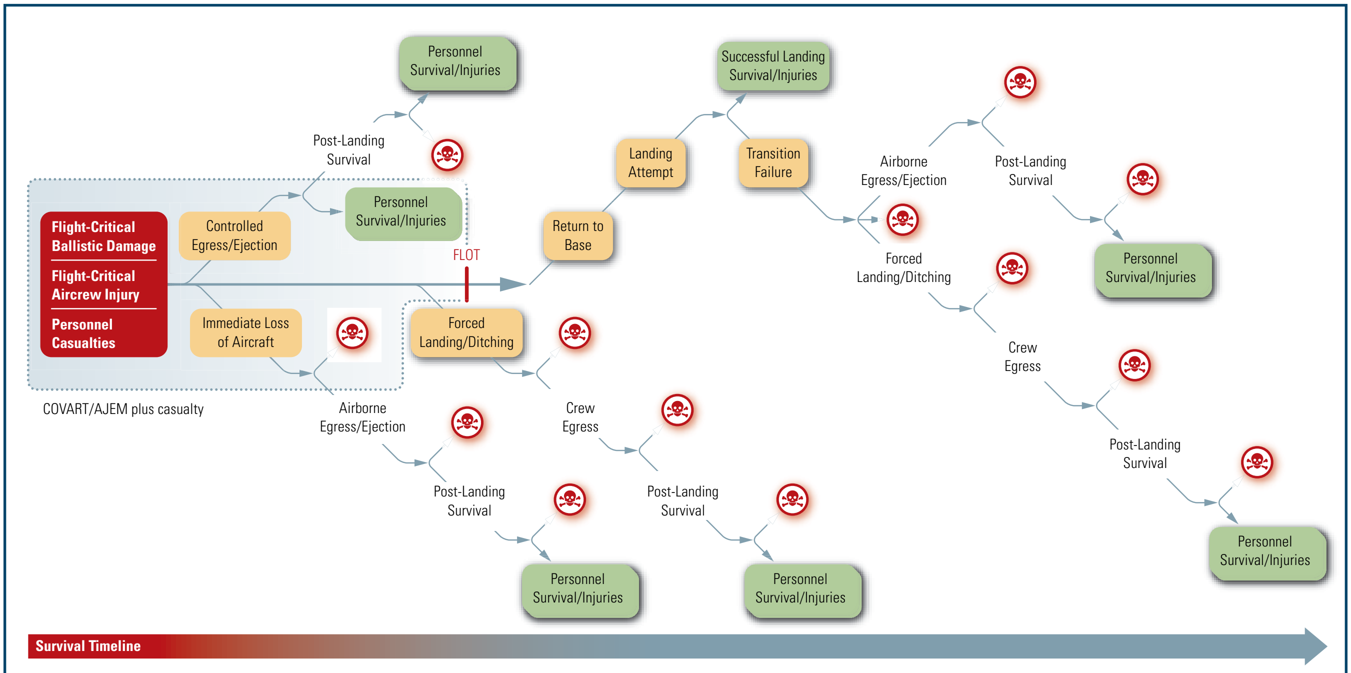

Figure 2 An Expanded Methodology to Assess All Aspects of Survivability

survivability issues that put aircraft survivability and casualty-reduction features into better perspective.

Finally, the casualty assessment must include the recovery of the aircraft at the home base, at some other friendly field or, if the situation dictates, in a forced landing off field or in the water. The additional risks in these possibilities, when compared to non-combat situations, arise from delayed effects from combat damage that manifest themselves after leaving the combat area or during the approach and landing events. For example, a small ballistic penetration of a fuel tank may not be recognized by a crew until it is no longer possible for them to reach their objective and too late to consider other alternative landing fields. Another example might be unrecognized damage to systems required for slow flight or landing (*e.g.*, flaps and slats) which might render the aircraft uncontrollable when they are deployed.

In considering the extended methodology in Figure 2, it quickly becomes clear that the approach could explode into an unlimited assessment, extending from immediate consequences to very long term issues. For crewmember survival after ejection, for example, one may consider surviving the ejection and landing events, survival after landing and until recovery, surviving the return to base and perhaps even the physical and mental aspects of the event on the

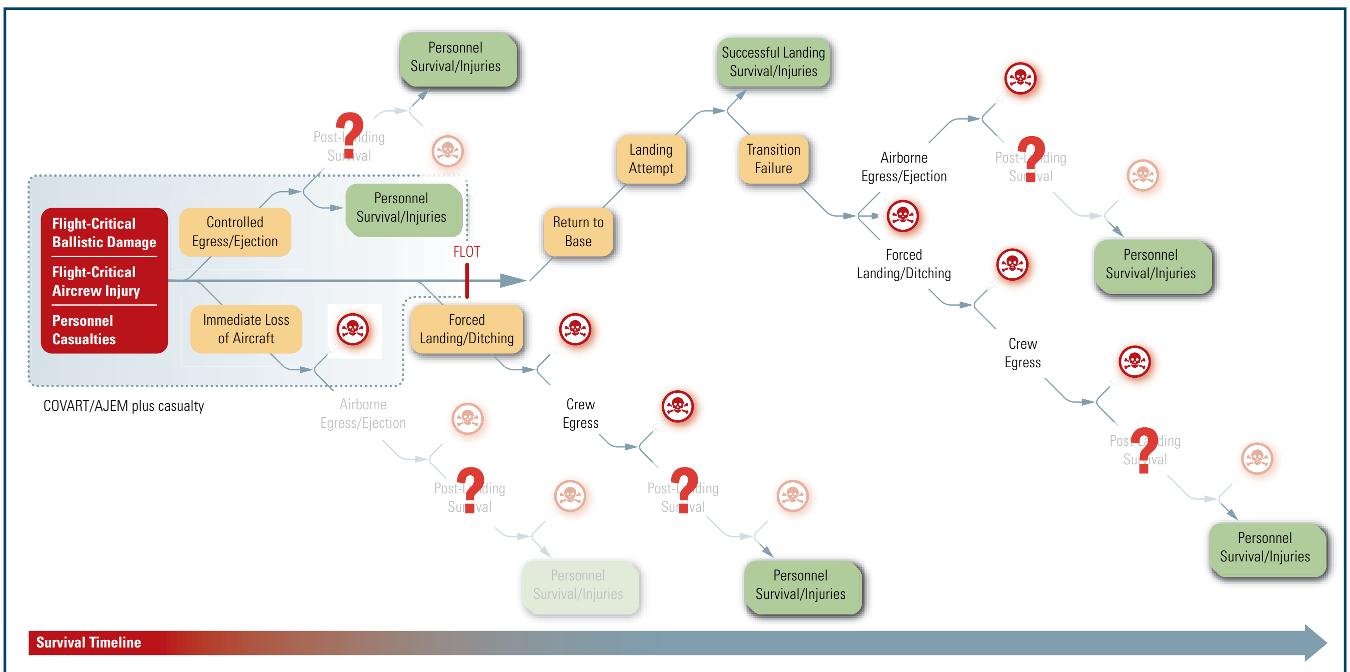

Figure 3 A Possible Abbreviated Version of the Expanded Survivability Assessment Methodology

Figure 4 Example JCA Casualty Assessment Scenarios

	Mission 1: Long Range Heavy Cargo	Mission 2: Short Range Troop Delivery	Mission 3: Low Altitude Air Drop
Takeoff	**Takeoff Profile 1 (Standard)** • Altitude and Airspeed: TBD • Time to Fly: 15 minutes then land • Fuel Load: 100% when hit • Load Carried: Heavy • Threats: 1, 2, 6, 7	**Takeoff Profile 2 (Steep Departure)** • Altitude and Airspeed: TBD • Time to Fly: 15 minutes then land • Fuel Load: 100% when hit • Load Carried: Full Troop Complement • Threats: 1, 2, 6, 7	Not Assessed Separately
Cruise (Mid Mission)	**Cruise Profile 1 (Standard)** • Altitude and Airspeed: High and Fast • Time to Fly: 30 minutes then land • Fuel Load: 60% when hit • Load Carried: Heavy • Threats: 3,4,5	**Cruise Profile 1 (Standard)** • Altitude and Airspeed: High and Fast • Time to Fly: 30 minutes then land • Fuel Load: 60% when hit • Load Carried: Full Troop Complement • Threats: 3,4,5	**Cruise Profile 2 (Low Altitude Drop)** • Altitude and Airspeed: Low and Fast • Time to Fly: 60 minutes then land • Fuel Load: 60% when hit • Load Carried: Medium • Threats: 1,2,3,4,5,6,7
Landing	**Landing Profile 1 (Standard)** • Altitude and Airspeed: TBD • Time to Fly: 5 minutes then land • Fuel Load: 10% when hit • Load Carried: Heavy • Threats: 1,2,6,7	**Landing Profile 2 (Steep Approach)** • Altitude and Airspeed: TBD • Time to Fly: 5 minutes then land • Fuel Load: 60% when hit (in hot zone) • Load Carried: Full Troop Complement • Threats: 1,2,6,7	Not Assessed Separately

individual's extended live span. The latter concerns would definitely seem to be beyond the scope of our interests, but the question remains as to how to limit the assessment. The bounds should be based on both the significance of the considerations and the difficulty in assessing them. The method should also be constructed with metrics that give reasonable credit for improvements to aircraft design that limit or reduce casualties. Figure 3 provides an example of some aspects of the extended casualty assessment methodology beyond immediate casualty considerations which might be questioned.

Another issue is that we may lack the technical capability to evaluate some of the elements of the extended assessment process. For example, it is not clear how one would assess the risk of surviving a parachute landing, even if environmental conditions are known. In this case considerable data may be available, but a research effort will be required to find and organize it to support the casualty assessment process. Alternatively, in some cases suitable methodologies may already have been developed somewhere in DoD or elsewhere and they only need be adapted to the casualty assessment process. Rather than starting from scratch, the JASPO methodology will include a search for existing methods and apply them to support the occupant casualty assessment process.

Prior to the JASPO initiative, some acquisition programs were beginning to develop their own methodologies for at least a qualitative assessment of casualty risk. One example is the Joint Cargo Aircraft (JCA). The JCA program Survivability Integrated Product Team (IPT) has been working on this process. In this case, a simplified assessment was created for several cases where the aircraft is attacked in different phases of flight. As an initial step, the team recognized the assessment would depend heavily on mission-related aspects such as geographical location, mission profile and aircraft configuration and loading as well as phase of the mission and the flight condition under which the ballistic damage occurred. The strategy, shown in Figure 4, was to evaluate seven distinct scenarios with different mission phases and cargo configurations. While this certainly does not provide results for all possible survival conditions, the phase and configuration choices cover a broad spectrum of mission segments that, when analyzed, should provide insight into many survivability and crew casualty issues.

The JCA process that has been proposed to evaluate these scenarios is shown in Figure 5. In this case, it is based on the Army's MUVES vulnerability assessment approach, but a methodology based on COVART could just as well be established for an Air Force or a Navy program. The initial step is to use the established vulnerability assessment process to

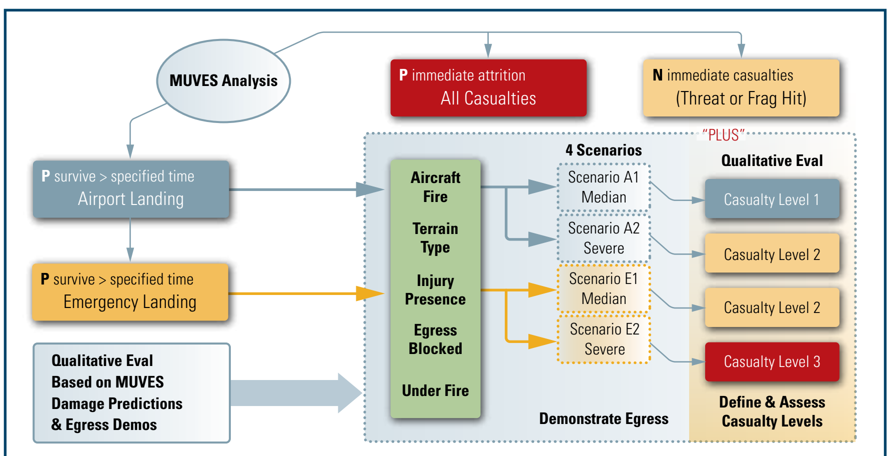

Figure 5 Potential "Short Term" Crew and Passenger Survivability (CAPS) Assessment Process

evaluate the likelihood of immediate loss of aircraft and crew (immediate attrition) as well as the likely crew and passenger casualties occurring immediately and directly from the ballistic encounter. The analysis uses Failure Modes Effects Criticality Analyses (FMECA) and Damage Modes Effects Analyses (DMEA) to identify the consequences of damage to or failure of components and systems that are critical for normal flight. The methodology normally considers critical flight crewmembers, but other crewmembers and passengers can easily be added for casualty assessments.

The next step is to examine delayed effects. If the aircraft is not lost immediately, it may be able to return to an airfield and land or it may be forced to land in unprepared terrain. The JCA team chose to select the landing environment based on available time of flight of the damaged aircraft. This can also come from assessments of damaged systems' residual capabilities as derived from the MUVES analysis. Using this information, a probability of returning to an airport or of making a forced landing can be determined. At this point the next steps are qualitative, since no analysis is currently available to provide the necessary information. For both airport and off-field landings, numerous elements could affect the likelihood of a "successful" outcome and the likely degree of crew and passenger injuries. The factors shown in Figure 5 are fire, terrain, pre-existing injuries (before the landing attempt), aircraft egress accessibility (it may be limited in an undamaged aircraft and made worse by structural damage, limited visibility due to smoke or darkness, or other factors), and the threat environment at the landing site. The methodology requires the assessors to consider these factors in establishing situations which would be "median" cases—those which might be the most likely outcome—and "severe"—those which would be the worst case given the initial scenario. These considerations are to be made for both the airport and off-field landing situations. Based on these considerations, a qualitative assessment of casualty levels is to be made for each situation. The exact definition of the levels remained to be defined in the process, but in any case the analysis creates only qualitative values.

This methodology is an initial step, required to fill a void where casualty assessments are needed. But, for a more permanent methodology, the process needs to be more rigorous and quantitative and relevant casualty data must be acquired and organized to support it.

The JASP project is a tri-service initiative to make an initial attempt to standardize the limits over which casualties are to be assessed and to define the methodology for an accepted casualty assessment. It will move beyond this process by developing a more quantitative interim methodology to address crew and passenger survivability though the crash and egress phases of a ballistically induced event and by developing a roadmap that will lay out the plan to finalize the methodology.

While the ultimate goal of the JASP project is to develop a methodology to include aircraft occupant casualty as a vulnerability design consideration, some key milestones of the project are as follows—

- A workshop will be held to discuss current data and methods related to crew casualty (vulnerability, safety, crashworthiness) and will also address capability gaps that need to be improved. Data collection efforts have begun which will identify and document existing data and models across the safety and vulnerability communities in support of the document. This task effort will coordinate with crew casualty and safety organizations throughout the three services. The Occupant Casualty Workshop is planned with key DoD agencies and representatives from the Federal Aviation Agency (FAA), the National Transportation Safety Board (NTSB), National Aeronautics & Space Administration (NASA), and the National Highway Transportation Safety Administration (NHTSA) to address and identify combat and mishap expertise, methodologies, modeling & simulation, and data that can be used to support aircraft occupant combat survivability assessments. The workshop will build upon the National Defense Industrial Association Casualty Workshop held in May 2008 and be the basis for the development of a State-of-the-Art Report (SOAR) that will lay the ground work for assessing occupant casualties during the acquisition program phase.
- The project will develop a CAPS analysis process that includes occupant survivability analysis through the crash and egress phases. The CAPS analysis process will be tested and an interim methodology will be updated with the lessons learned as the project proceeds.
- The project will solicit ideas and inputs from the survivability community, the warfighter, and acquisition experts. The project team members recognize that a broad range of survivability expertise resides throughout the three Services and that the success will depend on the knowledge and effort of all these communities. Ultimately, however, the assessment process must be accepted and used by the survivability community, and this approach must work towards gaining their buy-in.

There are numerous challenges that the project will face throughout execution. The project will need to define appropriate metrics that will allow occupant casualty to be measured along with the standard vulnerability considerations during the acquisition design phase. The metrics should allow for a fair trade-off between aircraft vulnerability considerations and occupant survivability considerations. The resulting methodology must be a credible and efficient process that will allow for timely assessments to affect aircraft design. The process must include enough detail to adequately consider aircraft attrition and occupant survivability yet be fast enough to respond to proposed design considerations during the developmental phase of the acquisition process.

The JASP project M-08-09-08 is a three year project designed to meet the challenges and address the DOT&E request for an occupant casualty methodology. This project will produce a methodology to allow occupant casualty to be addressed through the egress phase as part of the system level vulnerability analysis. It will also produce a roadmap to guide future improvements to the methodology. This CAPS analysis process will allow for occupant protection to be considered in conjunction with traditional vulnerability reduction designs. It will

Continued on page 22

Full Spectrum Crashworthiness Criteria

by David Friedmann and John Crocco

Within its scope of responsibility for DoD rotorcraft platform technology development, the Army Aviation Applied Technology Directorate (AATD) is investigating modern crashworthiness standards. Historical standards and mishaps are being reviewed, along with future requirements enabling technologies and analytical tools.

Crashworthiness requirements for military rotorcraft are defined by MIL-STD-1290A (AV) [1] which was cancelled in the mid 1990s but reinstated, without revision, in 2006. The Aircraft Crash Survival Design Guide (ACSDG) [2] provided the basis for MIL-STD -1290. The ACSDG defines a set of crash scenarios that can be survivable if an aircraft is properly designed. This guidance influenced the design of the AH-64 and UH-60 aircraft. Their performance in crash conditions shows a great improvement over previous generation helicopters. The ACSDG was first published in 1967 with revisions made in 1969, 1971, 1980 and lastly in 1989. MIL-STD-1290 was first published in 1974 and then revised in 1988.

Over the years, there has been repeated discussion about the need to revise crashworthiness design criteria. [3, 4, 5] There has also been recent discussion about crashworthiness qualification methodology. [6] With time, more mishap data becomes available; tactics, techniques and procedures change; new technologies are developed; and modeling and simulation capability improves. Also, limitations of existing guidance become more evident.

Today, there are multiple vehicles either in, or being discussed for development, such as various Class IV Unmanned Aerial Vehicles (UAVs), Joint Heavy Lift (JHL), Joint Multi-Role (JMR) and upgrades of current fleet helicopters. These aircraft will have to operate all over the world, in every possible environment during peacetime as well as both conventional and asymmetric conflicts. Mission payloads will vary between multi-million dollar sensor packages, troops and FCS vehicles. As we have seen with the current fleet, missions will evolve and change during the 50+ year service life of these future rotorcraft. Even current fleet rotorcraft will continue to grow in gross weight and fly different missions than for which they were originally designed.

Adequate guidelines do not exist to ensure crashworthiness of new generation aircraft. All attributes are tradable in a new aircraft design. The ability to compare the crashworthiness of one design to another is a difficult task that requires knowledge of mission requirements, relevant environments and customer priorities for survivability. A comparative metric along with adequate analytic tools needs to be developed to apply a systems approach to crashworthiness at minimum cost and weight.

Evidence suggests that military helicopters are flying lower and faster than anticipated in the ACSDG, and that most crashes do not occur at Structural Design Gross Weight on prepared surfaces. [7] Furthermore, past crashworthiness design guidance is applicable primarily to UH-60- and AH-64-sized helicopters and light fixed-wing aircraft. Work has been done to correlate helicopter size and mission to reasonable crash criteria, but it does not address very large rotorcraft and multiple impact surfaces. [8] Many questions exist regarding the right criteria to apply to very large new generation rotorcraft such as the JHL (Class VI), Class IV or larger UAVs that carry expensive payloads, or other rotorcraft not addressed by previous guidance.

The desired end-state of a full and complete crashworthiness criteria investigative and development effort is—

- Appropriate design criteria that accommodates different missions and classes of aircraft.
- Cost effective modeling and analysis methodologies leading to qualification by analysis and limited testing.
- Systems integration of technology and design features to achieve adequate level of crashworthiness at minimum cost and weight.

To that end, the Aviation Applied Technology Directorate is conducting several simultaneous efforts to develop crashworthiness criteria that will provide crash survivability over a broad range of aircraft size, gross weight, terrain, and mission profile.

The first of these efforts is a historical study of rotorcraft crash mishaps. AATD and SAFE, Inc., in coordination with the US Army Combat Readiness Center (CRC), are analyzing US Army rotorcraft crashes and developing analytical correlations that could potentially show trends in how rotorcraft crash, where rotorcraft crash, and how various configurations or systems affect crashworthiness. The study includes eight aircraft—UH-1, AH-1, UH-60, AH-64, OH-58, OH-6, CH-47, and the C-23 Sherpa. Variations in aircraft models (UH-60A *vs.* UH-60L) will be analyzed and trends in aircraft make (UH-1 *vs.* UH-60) as well as injury data to determine if there are common injuries based on aircraft makes, models, impact scenarios, or occupant locations. Identifying these trends is the first step in improving crash safety and survivability. With this trend analysis it may be possible to predict how various rotorcraft systems or design configurations affect crashworthiness.

In concurrence with the rotorcraft mishap analysis, AATD and the Center for Rotorcraft Innovation are working together to conduct five integral tasks required to develop new crashworthiness criteria.

These tasks are—

- The identification of design and environment implications on crash performance. This task will determine design accommodations that are necessary to provide crashworthiness on all surface types (hard, soft soil, water), and account for variability in operating weight and CG.
- The identification of system level design approaches that improve crashworthiness. This task will determine system approaches that reduce crash impact severity, provide increased crash resistance and energy absorbing capability, prevent occupant fatalities, and minimize the number and severity of injuries in a rotorcraft crash event. System level crashworthiness design approaches may include rotor systems, vehicle management systems / flight controls, landing gear and other external energy absorbers, occupant protection characteristics and structural layout.
- The identification and evaluation of current and on-the-horizon technologies that are required to meet new crashworthiness criteria.
- An extensive review of the applicability of current criteria to include the Aircraft Survival Design Guide as well as MIL-STD-1290A to include correlation with mishap trends.
- An assessment of current modeling tools to ensure they are capable of meeting the challenges inherent in the new criteria. In order for full spectrum crashworthiness criteria to remain cost effective, validation will rely heavily on modeling and analysis tools. This will require a capability to analyze and simulate a broad range of impact surfaces, failure mechanisms, and mission scenarios.

This work is being guided by a steering group of experts from industry and Government. This steering group includes members from the Air Force, Navy, NASA, and other US Army agencies including the Aviation Engineering Directorate, and Concepts and Requirements Directorate. Through the interworking of this group, fundamental aspects of crashworthiness are being challenged. Definitions are being clarified and a novel method of measuring the crashworthiness of a rotorcraft design is being investigated. Through a Crashworthiness Index, design features could be evaluated based on how they improve survivability across a broad spectrum of probable events and operating conditions. From this, a probabilistic approach could provide criteria that are based on the likelihood of an event occurring, and its relevance to the customer. For example, a water impact may be more likely and relevant to a naval customer and therefore those design features that improve survivability in those events would have higher priority. This approach also allows for flexibility so a design doesn't have to bear the weight and cost burden associated with accounting for all worst-case conditions.

The end result of this work will be recommendations for improved DoD rotorcraft crashworthiness design criteria. As the many parameters are balanced, including cost and weight, the safety of rotorcraft crews and troops is at the forefront. ■

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Crashworthiness—An Army Science and Technology Perspective

by Bob Hood and Bryan Pilati

Aircraft combat survivability, as defined by Professor Robert Ball, [1] is "the capability of an aircraft to avoid or withstand a man-made hostile environment." This concept can be broken down as depicted in Figure 1 below into Susceptibility, "the inability of an aircraft to avoid the guns, approaching missiles, exploding warheads, radars, and all of the other elements of an enemy's air defense that make up the man-made hostile mission environment" (mathematically described as the probability of being hit, P_H), and Vulnerability, "inability of an aircraft to withstand the man-made hostile environment" (mathematically described as the probability of being killed given a hit, $P_{K/H}$). Survivability (P_S) is hence mathematically defined as $P_S = 1 – P_H \cdot P_{K/H}$.

The reader should note that the textbook concept of aircraft combat survivability stops at the point at which either the *aircraft* has returned to base, or it has been "killed." This definition does not address the consequent *human* cost of aviation operations in terms of casualties, both injuries and fatalities. In addition, the man-made hostile environment sources of aircraft losses and subsequent human costs within this construct do not include mechanical failures, environmental factors, human error, and other causes that result in casualties and loss of aircraft. Moreover, it does not address the inherent risks associated with rotorcraft operations. The *crew and passengers* cannot simply eject from the rotorcraft, as they can from high-performance fixed wing aircraft, and parachute to safety. They are going to return to earth with the aircraft, and must endure whatever conditions the aircraft experiences.

The Armed Services have long recognized that rotorcraft crashworthiness is a critical factor in overall system design. The US Army Aviation Applied Technology Directorate (AATD) conducted study efforts in the 1960s that identified numerous opportunities to improve aircraft design. Many of these opportunities were implemented in the 1970s, resulting in injuries avoided and lives saved. These studies led to the development of the Aircraft Crash Survival Design Guide that was implemented in today's generation aircraft such as the AH-64 Apache and the UH-60 Black Hawk. These aircraft have, among other features, energy absorbing landing gear and seats; improved occupant restraints; crashworthy fuel systems; anti-plowing forward fuselage designs; high-mass subsystem retention; improved cabin rigidity; and crushable subfloor structures. All of these features are intended to maintain livable occupant spaces, attenuate crash energy incident upon the occupants and improve post-crash survivability; and have significantly reduced injuries and fatalities relative to Vietnam-era aircraft. Technology programs during the 1980s and 1990s developed inflatable restraint systems [*e.g.*, cockpit air bags, Inflatable Body And Head Restraint System (IBAHRS)], improved dual-sensing inertia reels to reduce fatal and injurious

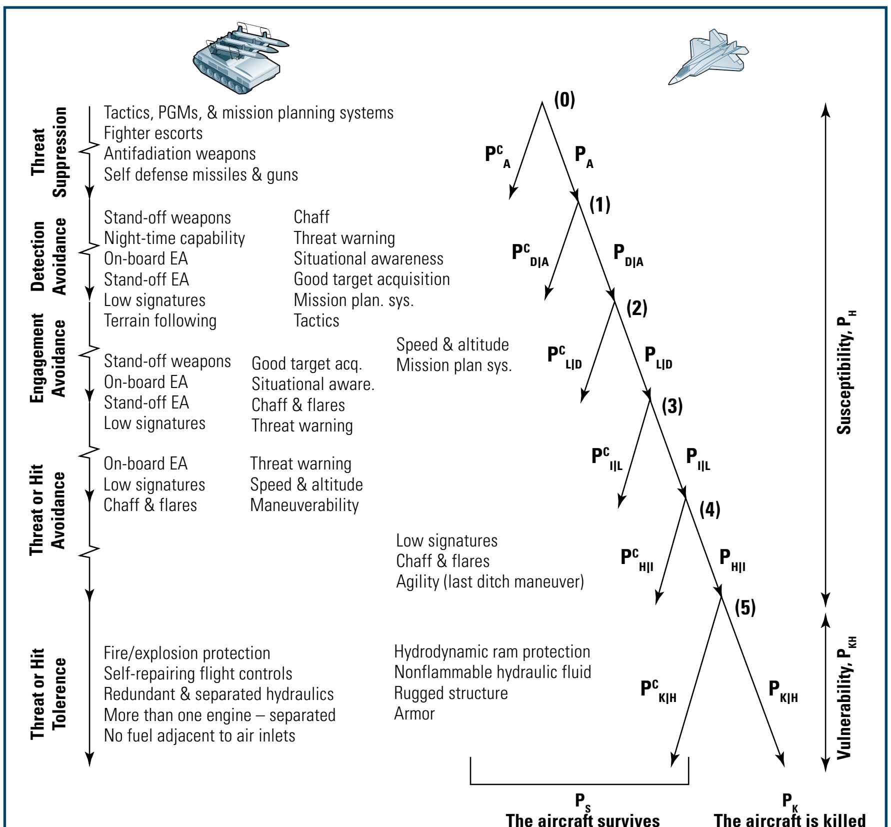

Figure 1

secondary impacts within the cockpit and cabin areas, and improved modeling and simulation tools to analyze the dynamics of crash events. Unfortunately, due to current fleet aircraft modernization programs that have resulted in increased weight and velocities, the effectiveness of these crash protection systems at higher impact energy levels has been reduced. Several airframe-unique efforts have been conducted to overcome gross weight and crew performance issues, such as the High Performance Shock Strut (HPSS) Program, and Helicopter Crewseat Cushion Program, respectively.

In addition to major technology development efforts in the last two decades such as the Cockpit Air Bag Systems (CABS) and the Survivable Affordable Repairable Airframe Program, AATD started an effort in 2008 under the aegis of the Aircrew Survivability Technologies (AST) Army Technology Objective (ATO) to develop technologies and design guidance that support both current fleet aircraft as well as future generation aircraft such as the Joint Heavy Lift and Joint Multi-Role Rotorcraft. Within the AST ATO effort, we are working in two key technology areas: 1) Conventional Threat Protection (protection against small arms fire, not addressed within this article), and 2) Advanced Aircrew Protection (otherwise known as crashworthiness). The crashworthiness efforts under the AST ATO include subsystems/devices technology development, and development of next generation crashworthiness design guidance (addressed within another article in this edition of Aircraft Survivability Magazine).

The objective of the Advanced Aircrew Protection program is to develop the next generation in crashworthy technology subsystems and control technology. In the past, crashworthiness subsystem designs have been passive in nature, designed to optimally attenuate crash loads at set aircraft gross weights, set occupant weights, and set sink speeds. Variance in any or all of the conditions leads to less than desirable performance. Prior research efforts (*i.e.,* Adaptive Landing Gear Concepts Program) strongly indicate that active crash protection offers high potential to reduce casualties and possibly even save aircraft and lives that would otherwise be lost. The primary approach is to step beyond passive device control concepts of the past, moving toward active sense and control concepts that simultaneously monitor and optimize the performance of individual subsystems, while continually synchronizing their contributions to overall crashworthiness, resulting in a synergism of protection to personnel and materiel. The current AST ATO program effort consists of two projects, 1) an overarching scheme to facilitate a network of communication and control among crash protection subsystems through common bus architectures, sensors, and algorithms, and 2) an active control crew restraint subsystem utilizing real-time adjustment to maintain proper occupant positioning and optimized motion control.

The first project was awarded to Boeing Integrated Defense Systems, Mesa, AZ, to develop an active sense and control network architecture that is intended to provide a platform for crash protection technology that is non-vendor specific (*i.e.,* open standard), so that the Government has choice in integrating desired technologies in a "plug and play" fashion. These technologies may also have a stand alone form for those legacy aircraft that do not incorporate integrated data bus technology. Although active control technologies are the primary focus, passive technologies may be used when considered to be the best alternative for a specific application. Some of the subsystems suitable for implementation of active control include seating systems, landing gear, external air bags, occupant restraints and supplemental restraints (*e.g.,* pretensioners, air bags).

The second project was awarded to MillenWorks, Tustin, CA, to develop active control subsystems to improve restraint of the occupants prior to and during a crash event. The first subsystem is a crew restraint technology incorporating three-modes of operation, 1) pre-pretensioning (a new capability) that applies *real-time sensing and tensioning* of the restraint webbing to remove slack from the spooled webbing *prior* to impact and a slight, nonintrusive continuous tension upon the occupant, 2) traditional pretensioning *via* a pyrotechnic device that spins the spool within the inertia reel to remove additional slack upon impact and assist in prepositioning the occupant., and 3) standard passive dual-sensing locking inertia reel functionality for false-safe operation. The second subsystem is an active head rest system that reduces lateral motion of the head by positioning a padded surface on either side of the occupant. Both subsystems would be connected through a stand alone controller or aircraft bus system incorporating suitable control logic.

In conclusion, significant crashworthiness improvements were developed and implemented following Vietnam in the current generation aircraft, but those improvements have been rendered less effective in reducing casualties by ever increasing aircraft gross weight and the subsequent impact velocities associated with crash. Technology being developed today has the potential to not only return crashworthy aircraft such as the AH-64 and the UH-60 to their original design levels of performance, but to increase that performance through active management of crash energy. ■

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DESCENT's Contribution to Rotorcraft Vulnerability Analysis

by Andrew Drysdale and Dr. Matt Floros

The vulnerability analysis (VA) of rotorcraft combat systems, which is a mission of the US Army Research Laboratory's Survivability/Lethality Analysis Directorate (ARL/SLAD), is a relatively complicated portion of the overall survivability analysis process. The execution of a VA requires engineer-supplied, case-specific model inputs to inform and modify the VA typified by a run-through of the MUVES/Advanced Joint Effectiveness Model analysis process. And because the inputs are critical for capturing the diverse vulnerability aspects of the target, their values must be determined accurately and systematically.

Accordingly, numerous engineering tools (*i.e.*, models and simulations) have been developed to complement subject-matter expertise in calculating the inputs. Among these tools, the DESCENT software package (not an acronym) is noteworthy for both its common application to rotorcraft survivability/vulnerability (S/V) analyses and, leveraging both longstanding ARL/SLAD development investment and current investment from ARL/SLAD and ARL's Vehicle Technology Directorate through a multiyear Joint Aircraft Survivability Program (JASP) project, its potential for even greater utility in the future.

Role in S/V Analyses

For each specific threat encounter in a MUVES VA, a set of procedures determines which components are damaged and which subsystems (*e.g.*, propulsion/engine) are affected by that damage. MUVES inputs known as "probabilities of kill given damage" ($P_{k/d}$'s) are used to express the type and likelihood of overall vehicle-level outcome, or kill category, produced by the component damage and subsystem degradation. DESCENT calculates $P_{k/d}$'s for rotorcraft damage cases involving partial or complete loss of engine power.

Rotorcraft kills are normally binned into three categories. Only the most severe, Attrition (AT), involves the permanent loss of the rotorcraft and/or crew. In a less catastrophic outcome, the rotorcraft might be forced to land immediately, make repairs, and then retreat to base. This category is the Forced Landing (FL) kill category. The final and least severe kill category is Mission Abort (MA). MA kills allow continued flight and a return to base for subsequent repairs.

Of great interest to analysts, then, is whether a given threat encounter can be predicted to result in an AT, FL, or MA kill. In power-loss cases, this is the role of DESCENT. DESCENT takes a helicopter of given aerodynamic and performance characteristics, its initial velocity and altitude, and the level of power loss the rotorcraft experiences due to the threat encounter under consideration and calculates whether sufficient power remains to allow the helicopter to fly away. In the event of total power loss, DESCENT attempts to simulate a reasonably "best-case" schedule of control inputs that approximate an autorotative maneuver. The impact velocity of the rotorcraft is then compared to a preset critical benchmark to determine whether an AT or FL kill results. Thus, a great deal of guesswork or reliance on manufacturer "dead-man's curves" devised for other situations is eliminated from $P_{k/d}$ calculation.

Flight Modeling Assumptions

DESCENT models rotor aerodynamics using blade actuator disk theory. [1] The rotor is a finite thrust-generating plane linked rigidly to the fuselage. Stall is accounted for by adding large drag penalties to the power requirement when rotor thrust nears a user-defined limit.

Dynamically, DESCENT is a two-dimensional (2-D) flight model. In other words, it models vehicle motion forward and vertically. Out-of-plane lateral motion is neglected, as is roll and yaw response. The main rotor disk has several degrees of freedom (DOFs)—collective blade pitch, represented by the variable thrust coefficient, and longitudinal cyclic. Cyclic pitch is rolled up with fuselage pitch to create a disk plane angle of attack quantity that expresses the cumulative effect of both quantities.

The implicit assumption that fuselage attitude (in all three DOFs) remains near the trim value throughout the duration of the flight path might seem inaccurate considering that DESCENT was created to deal with sudden loss of power situations. However, the 2-D model was judged to be necessary for keeping the code reasonably simple in the short term. Long-term development strategies for DESCENT include the eventual inclusion of out-of-plane controls and responses.

Execution Strategy

DESCENT is essentially an optimization code adapted from an algorithm for solving optimal control problems. [2] That is to say, it operates by iteratively minimizing an objective function that describes relevant aspects of the rotorcraft's state through its flight path and upon impact. This minimization is subject to two sets of constraints that are imposed throughout the analysis. The first is differential constraints, which describe the controls and the equations of motion (the physics of the problem). The second is non-differential constraints, which describe limitations of the rotorcraft controls, such as the maximum rate of change of the thrust coefficient.

Because the constraints are imposed at each iteration—and because the optimization sequence is not allowed to progress until the constraints are satisfied to a close tolerance—one feature of the optimization routine is that each successive iteration produces a valid result. Thus, DESCENT will not optimize an increasingly nonphysical or otherwise invalid solution. The tool limits itself to valid solutions as it chooses the most beneficial flight path toward the ground.

Objective Function and Constraints [3]

The objective function used by DESCENT is of the general form

$$\int_0^1 f\,dt + g|_1$$

where f describes the relevant rotorcraft quantities throughout the flight path and g describes the situation at impact. (Time, t, is non-dimensionalized by the duration of the flight.) For a typical analysis where an eventual impact is assumed, f takes the form

$$a\,(\omega\text{-}1)^2(1\text{-}\xi^4) + b(\mu_{horiz}\text{-}\mu_{min})^2(1\text{-}\cos(2\pi\xi)) + cd^2$$

where ω represents rotor speed (divided by maximum rotor speed) and d represents a descending advance ratio. The presence of ζ, a non-dimensionalized time quantity, minimizes the effect of the first term near the end of the flight path and the second term at both the beginning and end of the flight path. The variables a, b, and c are weighting parameters that can be used to easily customize the objective function. This customization ability means that rotor speed, horizontal velocity, and vertical velocity can be made more or less important relative to each other (or omitted altogether) as the analysis requires. In addition, any other rotorcraft quantity could be added according to the needs of the customer or the judgment of the subject-matter expert. The g function, meanwhile, normally consists of a straightforward addition of the horizontal and vertical velocity, weighted with respect to each other as desired, as evaluated at the time of impact.

The differential constrain equation is

$$\dot{x} = \theta\,(x,u,\pi,t)$$

where $\dot{x}$ is the array of state quantities (altitude, velocity, rotor speed, disk angle, *etc.*), u is the array of control quantities (disk plane pitch rate, engine torque level, *etc.*), and π is a parameter array used to non-dimensionalize certain quantities, such as time. The variable θ relates the change in rotorcraft state at each point in the time domain to the state and control variable values at that time. Meanwhile, a non-differential constraint array, S, describes limits on what values those control values can possess. When each row of S is zeroed to within a close tolerance, the non-differential constraints are satisfied.

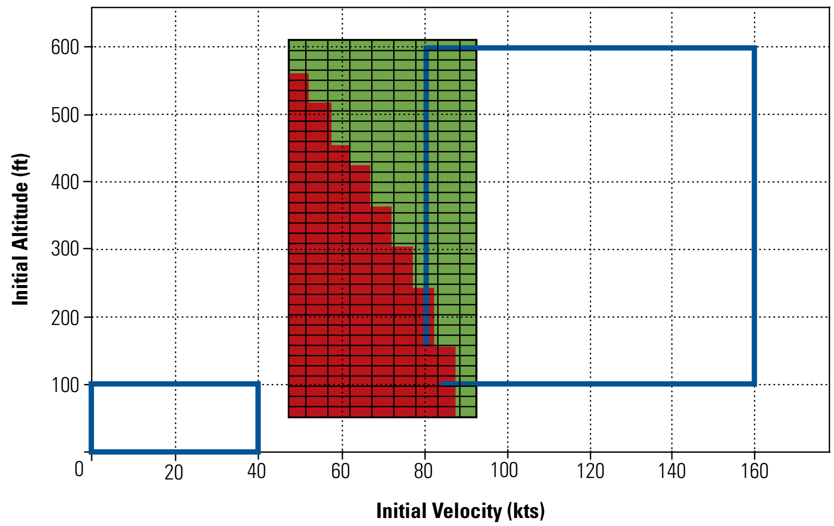

Figure 1 Typical DESCENT Graphical Output

Finally, there is a set of end constraints that describe certain characteristics that the finished flight path must take. These constraints are relatively straightforward. In the case of an eventual impact, the final altitude must closely approximate zero; and in the case of a successful fly-away, the rotorcraft's rotor must reach 100% rpm at cruising speed in level flight.

Results and Output

The most important quantity to optimize near the end of the rotorcraft flight path is its vertical velocity. This preeminence reflects the fact that most often helicopter crashworthiness is expressed in terms of a vertical velocity that can be sustained without irreparable damage. In addition to taking structural factors into consideration, the model often rates components such as crew seats and landing gear in terms of their maximum tolerated vertical landing velocity, so that this velocity (d in the analysis) becomes the primary output of the simulation.

In the case of an inevitable impact, the critical velocity that forms the boundary between FL and AT kill categories becomes the "target" at which the optimization aims. Should the impact velocity optimize to a value lower than this target, the optimization loop concludes and an FL kill is awarded. Alternatively, the iteration continues until no further improvement in the objective function is observed and an AT kill is the result.

DESCENT automates this process for each combination of initial altitude and velocity that form the analysis domain and stores results together in an array that corresponds to values on a height-velocity diagram. Typically, analyses are performed with two domain boxes in mind. The first is a "low/slow" domain, wherein the rotorcraft operates at a speed below 40 knots and a height above ground level (HAGL) of 100 ft. The second is a "high/fast" domain, wherein the rotorcraft is initially operating between 80 knots and its maximum forward flight speed and at 100 ft to 600 ft HAGL.

For each domain box, the number of height/velocity points corresponding to each kill category is divided by the total number of points analyzed to produce the $P_{k/d}$ for that kill category in that box. For example, if DESCENT runs more than 1,000 initial height/velocity combinations in the low/slow box and 350 of them return an FL kill, the low/slow $P_{k/d}$ is, in part, FL = 0.35.

Results are displayed both graphically, as shown in Figure 1, and numerically in the command window.

Future Work

While the current release of DESCENT produces suitable results for the needs of ARL/SLAD at this time, much work is being undertaken to improve the usability of the overall software package, the fidelity of its modeling, and the range of the model's capabilities. Current development is under the auspices of the aforementioned JASP project intended to add a number of features.

The primary short-term improvement is the incorporation of "non-optimal" response into the simulation. This incorporation includes a user-defined pilot delay (a short period where the controls are frozen before they are allowed to correct the rotorcraft state variables), options for additional limitations on vehicle capabilities (as defined in the S array) to represent progressive or unpredictable failure of additional onboard systems, and consideration of the possible divergence between the training of real pilots and the computer-predicted optimal control schedule. These features will combine to produce more realistic scenario modeling and give added confidence to DESCENT results.

By FY10, the focus of development will shift toward expanding DESCENT's applicability into the related field of crew casualty prediction. This expansion will be an important step toward considering the entire rotorcraft system in kill category prediction (*i.e.*, a relatively intact vehicle in which the crew is incapacitated cannot be easily repaired and removed from the impact site). It is, thus, important that crew safety considerations be integrated as tightly as possible into the survivability assessments of the overall rotorcraft. DESCENT already outputs information on impact velocity and orientation; a collaborative effort with the Naval Air Command and ARL's Warfighter Survivability Branch linking that output through a structural dynamics model to a human injury model will be the next important step in the ongoing improvement of the model.

Summary

The calculation of accurate and defensible $P_{k/d}$'s in a systematic manner is a crucial aspect of timely, reliable S/V analyses. DESCENT, an optimization code that works by iteratively improving a variable control schedule within a set of mathematical constraints, is increasingly important in the automation of this task. Its flexibility allows for user-definition of vehicle characteristics, mission details, kill criteria, and even modeling parameters. The next step in the evolution of DESCENT is incorporation of a link to crew casualty models. This linking, and the integration of variable vehicle characteristics and capabilities as well as variable pilot response characteristics, will give DESCENT output a wider range of applicability and a greater degree of confidence. ■

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Excellence in Survivability—Charles E. Frankenberger III

by Dale B. Atkinson

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Mr. Charles E. Frankenberger III for Excellence in Survivability. Chuck is a project engineer in the Vulnerability Branch at the Naval Air Warfare Center, China Lake, CA and is the lead for Vulnerability and LFT&E on the F 35 for NAVAIR and the F-35 Program Office. Chuck graduated from the University of Arizona in 1983 with a BS in Aerospace Engineering and has worked in the Systems Vulnerability Branch at China Lake since 1994 as the lead for turbine engine vulnerability.

As the lead for turbine engine vulnerability programs, Chuck worked turbine engine vulnerability issues for the V-22 and F/A-18E/F programs which required specific knowledge of turbine engine operation, vulnerability assessment methods, specific engine related vulnerability issues and vulnerability reduction techniques. Chuck served as test engineer supporting the V-22 and F/A-18E/F Live Fire Test programs conducting tests on the T406 and F414 engines. These tests provided early insight to the world of digital engine controls and the possibilities that exist with these new types of engine control.

In, 1995, the Navy was interested in pursuing turbine engine disk failures associated with ballistic damage. Through JLF funding, Chuck worked with Marty Krammer and other Weapons Survivability Laboratory (WSL) range engineers to design the spin fixture, a device used to "spin" engine components at operational speeds in an open air environment to conduct ballistic testing. Through this work, Chuck met with FAA personnel who were also investigating disk failures. This mutual interest led to an Interagency Agreement (IA) with the FAA Technical Center to conduct Uncontained Engine Failure Debris Analysis and Test activities. During this five-year $4.6M task, Chuck directed a small team of engineers to define the characteristics of an uncontained engine failure, collecting data in the field and working with the commercial aircraft industry, FAA, and NTSB to pull this information together. As part of the FAA tasking, China Lake was required to develop the Uncontained Engine Debris Damage Assessment Model, which was based on the Vulnerability Assessment tools COVART and FASTGEN. Efforts were coordinated with US and International commercial aircraft industry experts from the Aircraft Rulemaking Advisory Committee, Power Plant Installation Harmonization Working Group (PPIHWG). Products from this highly successful effort have been used within PPIHWG to develop analysis methods and data needed to revise the FAA's Advisory Circular 20-128A for multiple fragment threat analysis. The Uncontained Engine Debris Damage Assessment Model (UEDDAM) has been proposed by the FAA as a means of compliance to FAR 25.903 (d) rotor burst assessment. UEDDAM provided cost savings for DOD as reported in summer 2004 issue of the Aircraft Survivability Journal. During the C-5 Re-Engine Program, "In a unique approach to the problem, we were able to answer both LFT&E and safety issues by using the latest Federal Aviation Administration endorsed methodology. The use of the Uncontained Engine Debris Damage Assessment Model (UEDDAM) allowed the program to realize large cost savings while answering vital questions about the safety and vulnerability of the upgraded engines due to cascading damage."

At the conclusion of the initial five-year effort, Chuck coordinated a second five-year IA with the FAA to further NAWC involvement in the Catastrophic Failure Prevention Program. During this follow-on effort, Chuck coordinated the leveraging of funds from the FAA, Navy Propulsion RDT&E, NASA Glenn, and NAWC resulting in a very successful engine test, evaluating on-engine detection technologies. Chuck managed these efforts which have resulted in nine FAA technical reports being published to date.

In addition, Chuck represents NAVAIR as the Joint Aircraft Survivability Program (JASP) Vulnerability Subgroup Propulsion Committee Chairman providing team leadership and technical direction within the Tri-Service Community to address vulnerability reduction techniques for propulsion systems. Chuck has also been active in developing and directing JASP Projects as a Principal Engineer and the Survivable Engine Control Algorithm Development (SECAD) program has been one of the JASPO success stories. Through the use of digital engine controls, SECAD demonstrated state of the art engine damage detection and mitigation methodologies using production engine sensor and control hardware. Chuck directed a government and General Electric team through a five-year $2.4M, multi-phased program culminating in the successful development of a generic

methodology to detect engine gas path damage. Since the initial demonstration of this technology on the F414, the technology has been successfully applied to commercial high bypass ratio turbofan engines, and small helicopter turboshaft engines. Products of this effort included the SECAD methodology, as well as numerous reports and presentations to program managers and the international community through IEEE Symposium, which also resulted in an Aviation Week article on the SECAD program.

In 2001, Chuck joined the Joint Strike Fighter (JSF) team, and was named Propulsion Vulnerability and LFT&E Lead sharing responsibilities between the Propulsion IPT and Systems Engineering IPT. Early in the program Chuck worked within the program to assist in specification definition and TEMP development, and later worked with Lockheed Martin, Pratt and Whitney and the Fighter Engine Team to develop the JSF Live Fire Test Master Plan. Early testing under JSF was conducted on existing concept demonstration hardware including the 3 bearing swivel duct, LiftFan shaft, clutch and engine. These tests provided early insight to the vulnerabilities and robustness of the components making up the JSF STOVL propulsion system.

As JSF Propulsion Vulnerability Lead, Chuck is responsible for F135 and F136 contractor efforts addressing Survivable Engine Controls (SEC). This is an opportunity to transition technology developed under the Joint Aircraft Survivability Program to the JSF. In 2008, Chuck was named the Lead for Vulnerability and LFT&E on the F-35 (formally the JSF) for NAVAIR and the F-35 Program Office.

Chuck and his wife Kim, live in Ridgecrest, CA, with their three children Jaclyn, Chad and Darren. Chuck enjoys skiing, is a member of the National Ski Patrol, and volunteers at a local ski resort. Ski patrolling has provided an opportunity to take his family skiing most weekends throughout the winter.

It is with great pleasure that the JASP honors Mr. Charles Frankenberger III for his Excellence in Survivability contributions to the JASP, the survivability discipline and the warfighter. ■

The JASPO Casualty Assessment Initiative

Continued from page 13

allow for a timely analysis to objectively assess a platform's combat casualty performance, influence aircraft design during the developmental phase and ultimately reduce combat casualties. ■

Methodology for Assessing Tri-Service Personnel Casualties

by Patrick Gillich and Lisa Roach

Military system design features are sought that maximize the survivability of personnel without significantly compromising system effectiveness or lethality. Understanding personnel vulnerability is an important aspect of the design and evaluation of military platforms. For example, even if a vehicle's mechanical functionality is not impaired following a ballistic or blast event, its military value can be considered zero if the crew is unable to perform its assigned mission. Since 2004, ground platforms and weapon systems have been consistently evaluated based on crew survivability and/or lethality. The focus has moved from damage and performance degradation of the vehicle and vehicle components to injury and performance degradation of the crew.

The US Army Research Laboratory Survivability / Lethality Analysis Directorate (ARL/SLAD) currently conducts crew casualty assessments and system-level simulations for lethality, vulnerability and survivability studies directly supporting Live Fire Test and Evaluation (LFT&E) and Joint Live Fire (JLF) programs. Crew casualty assessment can be defined as the quantitative evaluation of personnel vulnerability in terms of injury and/or the resulting operational degradation. These assessments utilize field data from test surrogates or an experimental characterization of a threat to estimate casualties. LFT&E and JLF testing is often complimented with modeling and simulation to perform pre-shot predictions or to support different scenarios that are of interest but not tested.

Evaluation of military aircraft survivability has historically focused on damage and performance degradation to the aircraft in a combat event, with limited consideration of personnel casualties. In November 2007, the Director of LFT&E, in a memorandum to the Joint Aircraft Survivability Program (JASP), mandated a change in this evaluation methodology to include a focus on the "assessment of aircraft crew and passenger casualties to the point of safe return or egress." This includes the "evaluation of personnel casualties due to combat-related in-flight escape and crash events." To support this mandate, aircraft designs that incorporate casualty-reduction technologies such as armor protection systems, energy attenuators, smart landing gear, advanced restraint systems and crashworthiness designs must be identified, understood and evaluated. Use of post-incident investigation aids in the determination of the causes and types of crew and passenger casualties necessary to evaluate aircraft survivability in combat and crash scenarios. An important portion of system evaluation involves crew casualty evaluation of actual crew compartments for specific situations. The evaluation of crew and passengers in aircraft necessitates the use of complimentary modeling and simulation that support the interaction of the threat and target.

The Operational Requirement-based Casualty Assessment (ORCA) personnel assessment methodology supports aircrew survivability from conventional threats and protection in survivable crash conditions (Figure 1). ORCA originated in 1992 from the tri-service analysis community through an effort led by the Office of the Director, Operational Test and Evaluation to examine the methods and data applied by the services to assess casualties. A working group representing key government and industry players provided technical input and review during the concept phase and initial implementation of what became the ORCA methodology. Represented were the armed services (Army, Navy, and Air

Crew Casualty (stand-alone ORCA)
Personnel Assessments using field data from test surrogates or experimental characterization of threat to estimate casualty.

Example Usage: System evaluation, LFT&E test shot assessments

System Level Analysis (embedded ORCA)
Predictive analysis of personnel effects for military munitions and platforms simulating ballistic and blast event environments.

Example Usage: LFT&E pre-shot predictions, supplemental modeling of untested events, battlefield event re-creation

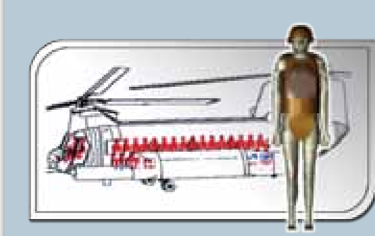


Figure 1 Applications of Personnel Methodology

Force), Office of the Secretary of Defense (OSD), Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), Joint Aircraft Survivability Program (JASP), medical community, other government agencies, academia, and industry partners. ARL/SLAD has and continues to develop and improve this state-of-the-art personnel vulnerability framework.

The key tenet of the ORCA methodology is incorporation of existing community-accepted models, applicable to each insult type, into a consistent framework to allow combined assessment of casualties for all threat types across all platforms. For example, the Army's ComputerMan model is used to evaluate penetrating injuries, while BURNSIM, an Air Force model, is used to assess the likelihood of skin burns from thermal exposure.

The following are some basic terminology routinely used in defining and reporting crew casualty assessments.

- **Incapacitation—**the inability to perform, at a level required for combat effectiveness, the physical and mental tasks required in a particular combat role at a specific post-wounding time.
- **Serious Injury—**an injury that requires timely medical attention. Untreated serious injuries could deteriorate and cause loss of life.
- **Medical Casualty—**an individual who has experienced an injury which requires evacuation from his/her unit so that medical treatment can be administered.
- **Operational Casualty—**an individual whose performance is less than what is required for combat effectiveness. This individual may or may not require medical attention and may or may not be a fatality.

In support of crew casualty analysis, different data collection techniques are employed depending on the expected outcome of a test event. For example, ballistic plywood mannequins appropriately dressed are used as personnel surrogates when assessing penetrating threats. Damage to the ballistic mannequins is translated into inputs for fragment penetration analysis within ORCA. Other techniques are employed to capture the necessary information to assess thermal, toxic gases, blast overpressure, and abrupt acceleration. With this engineering data as input, casualty metrics are computed using the ORCA model.

ORCA is a high-resolution computerized human vulnerability model that can be used to assess the impact of various casualty-causing insults on military personnel including blast overpressure, penetration, toxic gases and chemicals, thermal, directed energy, abrupt acceleration and blunt trauma. ORCA calculates several injury severity trauma metrics that may be used to characterize both an individual injury as well as multiple injuries to a single person. Injury severity scoring systems provide the analytical tools to accurately characterize both the medical injury and the injury severity with respect to survivability. ORCA is also used to assess various casualty-causing mechanisms and their effect on the ability of military personnel to perform battlefield tasks. It considers the operational tasks that personnel are required to perform, and determines the extent to which penetration and other insults degrade the ability to perform these tasks. The model can be applied to personnel occupying any crew position and posture on any combat platform.

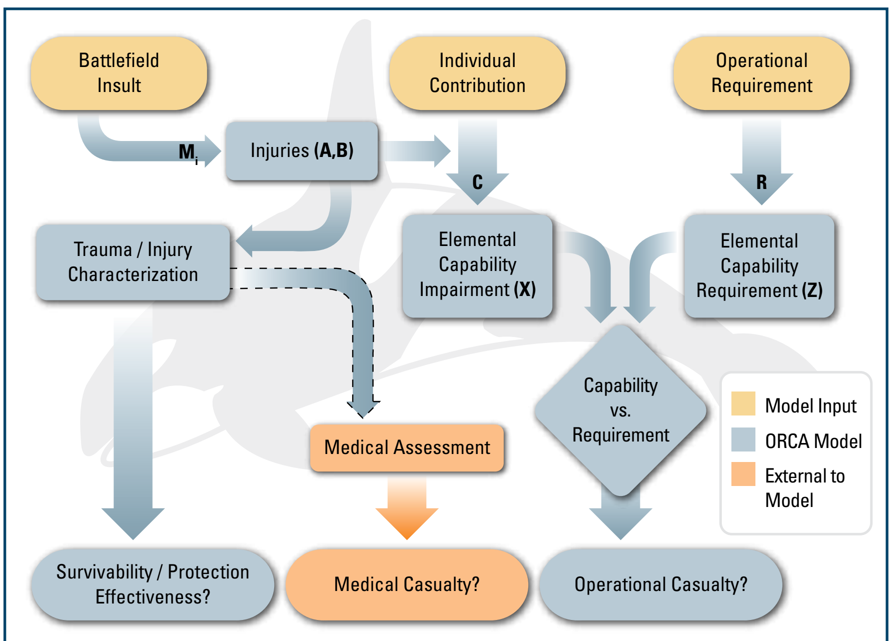


Figure 2 ORCA Methodology

The ORCA personnel assessment process is illustrated in Figure 2 and begins with characterization of one or more battlefield insults. Next, the resulting injuries and their associated severities are computed for the insult(s). These injuries are recorded in a standard format which takes into account the various types of biological tissue damage. In addition to direct physical damage to tissue, ORCA models the deleterious physiological processes initiated as a result of anatomical damage, such as bleeding and sepsis. Anatomical injuries are mapped to a standard trauma characterization by injury type and severity to facilitate survivability assessments.

The operational casualty assessment process continues by mapping the physical injury to the predicted impairment of human capability at various post-wounding times as represented by an elemental capability vector (ECV) of cognitive and physical capabilities. The post-injury capability is then compared to the required capabilities (using the same scale) associated with the individual's military job, task, or mission to evaluate operational impairment.

ORCA is embedded into the Advanced Joint Effectiveness Model (AJEM) as the personnel assessment model for system-level predictive analysis, capable of evaluating threats against single rotary or fixed wing aircraft and ground-mobile targets. AJEM has a history of use and acceptance in the evaluation of vehicle and personnel vulnerability. Figure 3 depicts several of the inputs required and pertinent outputs generated in an AJEM analysis. Both the AJEM and ORCA models are used during all phases of system acquisition from research, design, and development to production, test, and evaluation and have been verified, validated, and accredited for major acquisition programs. The capabilities of AJEM are fully integrated into

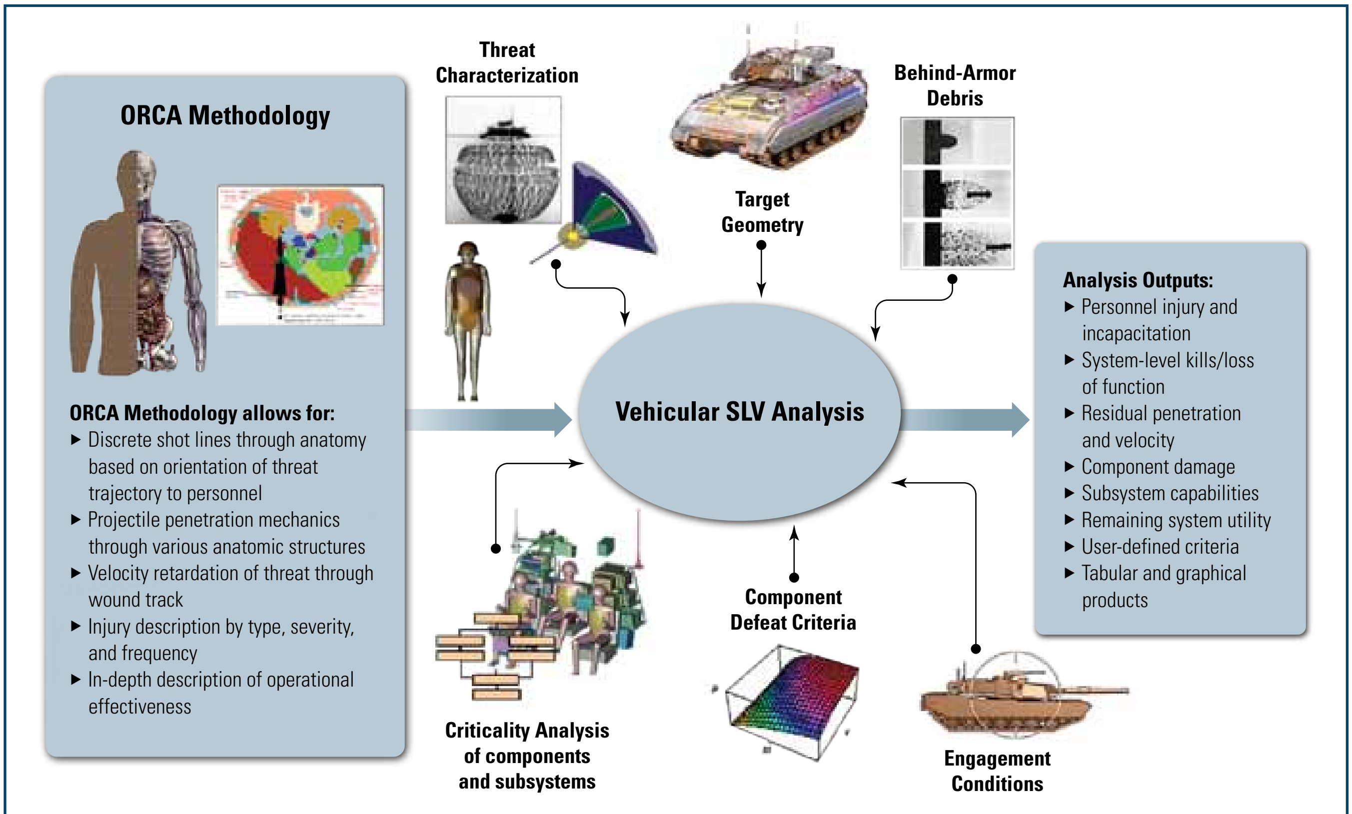


Figure 3 AJEM Model with Embedded ORCA

the test and evaluation (T&E) process from concept design to production milestone decisions for tri-service lethality, vulnerability, and survivability evaluations.

ORCA methodology development, model management and configuration control is currently led by ARL. Configuration Control Board meetings are held periodically and include representation from the Army, Navy, Air Force, JTCG/MEand several Survivability / Lethality / Vulnerability (SLV) model representatives. The current release of ORCA has been accredited by the US Army Test and Evaluation Command (ATEC) for assessing the effects of penetrating fragments, blast overpressure, and abrupt acceleration on personnel based on verification and validation performed in support of LFT&E system evaluation. It has been accredited for the Spider and Excalibur systems for lethality evaluation and the Family of Medium Tactical Vehicles (FMTV), High Mobility Artillery Rocket System (HIMARS), and High Expanded Mobility Tactical Truck (HEMTT) for survivability evaluation. Several model accreditations are currently in progress and include the High Mobility Multi-purpose Wheeled Vehicle (HMMWV), Mine Resistant Ambush Protected (MRAP) family of vehicles and the Guided Multiple Launch Rocket System (GMLRS).

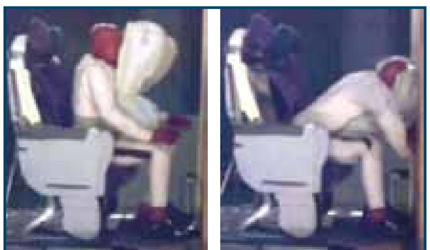
In addition to its role as the standard methodology for evaluation of casualties for Live Fire Test programs, it is currently used for several high profile programs. For example, the ORCA methodology is currently being used to support battlefield event recreation for the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) program, of which several organizations within the Department of Defense are partners. The goal of the JTAPIC program is to improve the understanding of vulnerabilities and to develop solutions that will prevent or mitigate blast-related injuries. Additionally, ORCA is being used to support the Program Manager-Maneuver Ammunition Systems (PM-MAS) small caliber ammunition program for estimating round lethality. This program takes advantage of ORCA's shotline and anatomic resolution to simulate round performance from the shooter to the target.

ORCA provides a current and consistent methodology for SLV personnel assessments. As the only accredited shotline resolution personnel analysis tool, it is well situated to serve joint-service personnel analysis needs. Casualty reduction technologies planned and currently fielded require high resolution to evaluate the tradeoffs in the SLV space. ORCA provides a consistent framework for the assessment of casualties for battlefield insults, applying joint-service community accepted methodologies, while remaining extensible to handle new and improved insult models with sufficient resolution. ■

Surviving an Aircraft Crash with Airbag Restraints

by Thomas Barth

Inflatable restraint solutions have improved the survivability of commercial transport and civil General Aviation (GA) aircraft by mitigating impact injury and keeping the occupants conscious and able to evacuate quickly. The AmSafe® Aviation Airbag makes advanced occupant crash protection systems feasible for retrofit into existing and space-constrained cabins/cockpits. This technology has not been incorporated into military aircraft as it is challenging to configure and qualify the equipment for Department of Defense specifications. A look at the history and field performance of the AmSafe Aviation Airbag illustrates the factors to be considered and the potential benefits for military aircraft.



100 ms (left) vs. 140 ms (right). The AmSafe Aviation Airbag functions during a 16g, 180ms impact. It is installed in the front row economy behind a bulkhead.

Transport Aircraft Interiors

The AmSafe Aviation Airbag entered service on commercial aircraft in February 2001. The first use was for transport aircraft that needed to comply with the improved crash safety regulations of FAR 25.562. [1] These regulations introduced dynamic loading requirements for aircraft seats in 1988. Dynamic impact tests with an Anthropomorphic Test Dummy (ATD) are now common to ensure that all civil aircraft seats and floor attachments comply with the FAR 25.562 regulation. The Head Injury Criteria (HIC), a measure of injury potential from head impact, was introduced with the FAR 25.562 regulation in 1988.

Airbags can absorb and distribute high levels of impact energy and were immediately considered for HIC and improving safety. Certifying the technology for aviation use, however, required years of development to satisfy a wide range of requirements including electrical (such as EMI/HIRF and lightning strikes), mechanical (such as vibration and structure), and other environments (such as temperature, humidity, and altitude exposure). A well-planned and novel compliance approach met the requirement that safety devices on aircraft be extremely reliable. It also showed that the system functions for the full range of occupants and uses without impeding evacuation. All of this had to be done in a package to retrofit into existing interiors and had to meet the aggressive cost and weight targets for commercial aviation.

In the AmSafe Aviation Airbag configuration, the airbag is mounted onto the restraint and has modular components with highly adaptable attachments. This configuration meets the requirements of both design and market acceptance. Aircraft that use this configuration can greatly expand the flexibility of the interior design. Many new premium-class interiors are possible only because the airbag mitigates occupant flailing and because it passes injury prevention requirements.

General Aviation / Light Sport

Dynamic performance standards were also adopted for GA aircraft in 1988 with FAR 23.562. [2] The new regulation impacted GA aircraft less than transport aircraft. The FAR 23.785 [3] regulation already required shoulder restraints. The minimum injury prevention requirements for GA aircraft can generally be satisfied without an airbag. Improved crash protection, as opposed to HIC compliance, was the motive for introducing the AmSafe Aviation Airbag in GA and Light Sport aircraft. GA aircraft have a much higher accident and fatality rate than transport

Airbag protection from impact to side-mounted furniture in a premium seat mounted at an angle to the aircraft axis.

The AmSafe Aviation Airbag's four-point configuration used for GA aircraft.

aircraft. Accidents are 28 times more frequent and fatalities 26 times higher in GA aircraft based on ten years of statistics from 1997 to 2007. The statistics compare accidents per 1 million miles flown and fatalities sustained for part 121 and 91 operations. [4]

The AmSafe Aviation Airbag was certified both for the pilot/copilot and rear passenger seats on various GA and Light Sport aircraft beginning in 2004. The system is widely used in the production of single-engine GA aircraft. Since 2007, the airbag has been installed as standard equipment on about 80% of new single-engine aircraft.

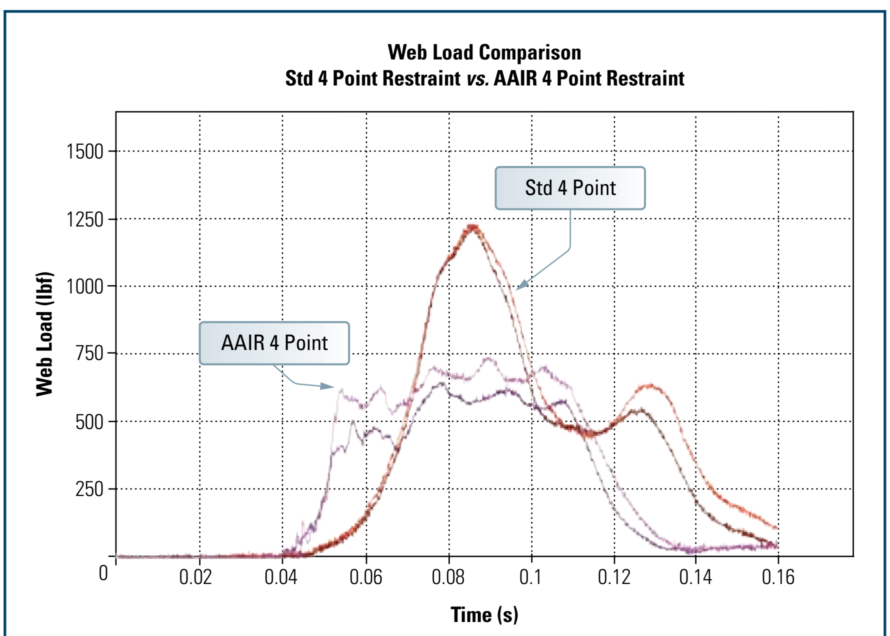
Pretension / Flail Mitigation

Airbag designs use the energy-absorbing capability differently depending on the interior design. The images from dynamic tests shown previously in this article use the bag predominantly as a barrier between the occupant and the structure. A spring/damper analogy can be applied to the barrier bag concept. The occupant hitting the bag is resisted by increasing air pressure, essentially creating a pneumatic spring. The maximum compression of the bag occurs before the occupant's head hits the interior structure. The venting of the bag acts as a damper, reducing the rebound and dissipating the energy through the air flowing out of the bag.

The tubular AmSafe Aviation Airbag four-point restraint compared to a standard four-point restraint.

A tubular three-point restraint compared with a standard three-point restraint in a lateral impact.

Other applications use the bag differently. The bag can distribute restraint loads to the occupant early in the event, reducing the momentum caused by the occupant articulating forward. This reduces the peak seatbelt forces, spreading them over a longer time interval.



A restraint web load comparison between the tubular airbag four-point restraint and a standard four-point restraint.

Airbag configurations offer two benefits—a reduction of the flailing envelope (zone in which the occupant may contact aircraft structure) thus avoiding potential body impact to the structure; and the reduction of seatbelt force applied to the body.

Side-facing seats are used in limited but important configurations. Troop transport, medical evacuation, and other special vehicles require seat positions exposed to lateral impact forces. The body is more susceptible to non-longitudinal impact forces. The same airbag benefits apply for lateral impacts.

A three-point restraint with a tubular bag incorporated into the shoulder harness eliminates body-to-body contact and head impact with structures just a few inches away from the head, as shown in the above figure.

The benefits and a wide range of applications are not conceptual. Restraint-mounted airbags have been in service for more than a decade. US Army aircraft make limited use of systems such as the Inflatable Body and Head Restraint System (IBAHRS), originally developed in the early 1990s by Simula Inc. (now part of BAE Systems). Early systems used older, solid propellant inflation technology. The heat generated by the inflators limited bag designs and prevented these systems from reaching a wider market. The AmSafe Aviation Airbag system was first developed in the late 1990s and began revenue service in commercial aircraft in early 2001. The system has since gone through several design iterations and uses a range of modern compressed gas and hybrid (compressed bag/pyrotechnic) inflator technologies.

Iberia Airlines A340-600 overshot the runway in Ecuador. There were no injuries. AmSafe Aviation Airbags did not deploy. [5]

The Cirrus SR22 crashed and slowly broke through trees. There were no injuries and the AmSafe Aviation Airbags did not deploy. [6]

The Cirrus SR22 crashed upon takeoff. There were no serious injuries and the AmSafe Aviation Airbag deployed upon impact. [7]

The Cirrus SR22 crashed upon approach. AmSafe Aviation Airbags deployed and occupants with serious injuries evacuated. [8]

Experience in the Field

More than 37,000 AmSafe Aviation Airbag systems have been produced and are flying in more than 6,000 aircraft. The airbag is certified on every major transport aircraft platform and is used by over 30 airlines worldwide. The GA and Light Sport aircraft applications are more recent. Standard installations began in late 2005 on aircraft such as Cessna 172/182/206 and Cirrus SR20/SR22. The number of commercial aircraft equipped with AmSafe Aviation Airbags is expanding rapidly. Installations averaged more than 130 GA aircraft per month in 2008. Since the first commercial accident with an air bag-equipped aircraft in late 2005, there have now been over 50 accidents monitored by AmSafe.

Minor Accidents

The accidents can be classified according to the injury potential and if the AmSafe Aviation Airbag system deployed. Minor-injury accidents generally do not have sufficient impact force to cause deployment. A typical example is veering off the runway. These accidents are not always minor from an aircraft damage perspective. The AmSafe Aviation Airbag has demonstrated appropriate activation thresholds and no inadvertent deployments have been recorded.

Another example of a more serious accident, but one with only minor injury potential, occurs if the impact is dissipated progressively. The AmSafe Aviation Airbag crash sensor activates only on an impact large enough to threaten serious injury.

Major Accidents

Deployments in the field have also indicated the appropriate crash sensor threshold. They have occurred in accidents where the potential for serious injury existed but only minor injury occurred. The AmSafe Aviation Airbag has deployed in the accidents where serious injuries have occurred. There have also been serious/fatal and non-survivable accidents.

Accidents have occurred with the airbags deployed, and the occupants were able to evacuate the aircraft despite having sustained serious injury.

Potential Military Applications

The restraint-mounted design and modular components of the AmSafe Aviation Airbag system make it adaptable to a wide variety of cockpit and cabin configurations. Most of the current applications were retrofitted into existing aircraft interiors. The AmSafe Aviation Airbag system has great potential for the constrained space of military applications. The modified restraint eliminates the need to incorporate an airbag module into the cabin or cockpit structure. The bag can be positioned right where it is needed, accommodating a wide range of occupant sizes and personal equipment (such as combat gear). Military specifications have more stringent environmental requirements and impact parameters. The AmSafe Aviation Airbag components can be adapted for the specifications with upgrades to items such as electrical cables and connectors. The inflation and bag performance of the system can be configured to military impact environments just as the system is currently designed for each unique interior and civil aircraft type. Crash sensing for various military aircraft depends on the aircraft type and the impact environment. Some applications, such as helicopters, require that the sensing system be modified so that it can appropriately discriminate inputs from various directions. ■

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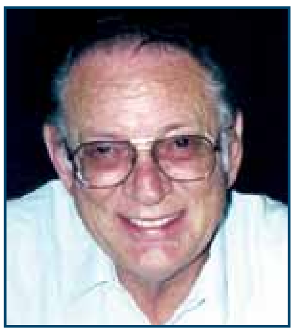
Pioneer in Survivability—Walter S. Thompson III

by Eric Edwards

On 15 April 2005, the survivability community quietly lost one of its national assets with the passing of Walter Thompson. And quiet is just the way the soft-spoken 70-year-old would have wanted it. Still, "Mr. Engines"—as Walt was often called—was considered by many to be the world's most knowledgeable expert in turbine engine vulnerability. Furthermore, he spent four decades testing, analyzing, and documenting a wide range of aircraft survivability and related issues; and he was an innovator of many test/assessment methods now standard in the survivability discipline. Thus, the JASP is honored to posthumously recognize Walter S. Thompson III as one of its Pioneers in Survivability.



The Early Days

Born in 1935, Walt grew up in the outskirts of Philadelphia. "From an early age," said Jeanne Thompson, his wife of 45 years, "Walt was a good artist. He said the trick was just to draw what you saw." Walt especially liked to draw mechanical systems, such as cars, trains, and airplanes—particularly the airplanes fighting in World War II at the time. This early interest in military aviation as well as his keen attention to detail would not only lay the foundation for his eventual profession but would also characterize the youth-like enthusiasm and artistic eye that Walt brought to projects throughout his career.

Walt earned a bachelor's degree in mechanical engineering from Drexel University in 1958 and shortly thereafter enlisted in the US Army (later transferring to the National Guard). In 1960, Walt got married and began working as an aerospace engineer for the Glenn L. Martin Company (now Lockheed Martin) in Middle River, MD. He was at Martin for two years, producing facility systems integration layouts for a Titan missile launch complex. Walt then spent three years at the US Air Force Logistics Command at Olmsted AFB in Pennsylvania, where he worked on Air Force flight and navigation instrumentation systems.

In 1965, Walt's career finally found its home at Aberdeen Proving Ground in northeastern Maryland. He initially worked on performance/endurance evaluation projects for the M151 MUTT (or jeep) at the US Army Development and Proof Services. But his interest in aviation was not to be denied. And a year later he joined the Vulnerability Laboratory of the US Army Ballistic Research Laboratories (BRL) (now the Army Research Laboratory [ARL]) and began working in aircraft studies. Walt didn't know it then, but he would work survivability projects at this organization as a Government employee for more than 30 years and then as a contractor for another 8.

BRL: The Emergence of "One-More-Shot Walt"

Four decades is a lot of time to have accomplishments, and Walt had many of them while at BRL/ARL. An innovative tester, intuitive analyst, prolific writer and presenter, trusted consultant, and consummate mentor and teacher—Walt seemed to be able to make a positive impact on a project whenever and wherever he touched it.

"He had the most genuine love of the business of anyone I've ever known," said long-time coworker and friend Steve Polyak. "He lived and breathed aircraft survivability." Bill Keithley, another coworker and friend, agreed. "Walt was not one of those guys who walked out the door at the end of the day and forgot about a problem he was working on," he said. "Sometimes, when I would arrive in the morning, Walt would be waiting with the answer. He had worked on it all night."

Keithley also noted that, in his early days at BRL, Walt teamed up with a group of like-minded innovators, including Jim Foulk, Roland Bernier, Walt Vikestad, Don Mowrer, Dennis Bely, and Ray Wheeler (as well as Keithley himself). "This cohesive team was a group of technically solid, no-frills engineers and technicians who worked well together and accomplished a lot." Walt and the team were widely known for their ability to gather target aircraft for testing, exploit the vulnerability, and develop vulnerability reduction (VR) solutions. Even more importantly, they were highly successful in making their knowledge and lessons learned available to all who might benefit, including aircraft developers, all the military services, and the DoD. Of particular note, Walt became an expert at assembling movies (and later videos) of test results and using some of his artistic skills to communicate vulnerability points and the major lessons learned.

One especially effective partnership Walt had was with Jim Foulk on the Black Hawk helicopter program. Walt was the Government's lead test engineer on the program, and Jim had left BRL to become the head of Sikorsky's Safety and Survivability (and then Systems Engineering) division. The two men worked closely to ensure survivability requirements were included and met in the design, development, and testing


The Survivable Black Hawk Helicopter and T700 Engine

processes. "With Walt at BRL and Jim at Sikorsky," said Keithley, "they were a double-edged sword."

In addition, Walt had a distinct passion for learning about the vulnerability of adversary aircraft. And he had an amazing ability to acquire foreign targets, especially Soviet aircraft, and effectively exploit them by systematically performing many controlled damage and selective ballistic tests on a limited number of assets. "He probably knew more about the vulnerability of Soviet aircraft than the Soviets themselves," said Foulk.

Although Walt worked on many types of ground and air systems (even a Navy hovercraft) throughout his career, he will likely be remembered most for his expertise in the vulnerability of turbine aircraft engines (thus the nickname "Mr. Engines") and drivetrains. Perhaps his most significant contributions came in the development and vulnerability reduction of the T700 engine, which is used in the multi-Service H-60 helicopter series and other aircraft today. "When it came to survivability," said Polyak, "the T700 really was Walt's engine. And he didn't just study it; he made it a lot better."

Walt's equally strong passion for testing also earned him another nickname. "We called him 'One-More-Shot Walt'," said Polyak, "because he always seemed to want to do just one more test. His philosophy was that 'nothing leaves the range alive.' Every piece of aircraft hardware had some testing value, and Walt always worked to get the maximum utilization out of what we had to work with."

Accordingly, Walt caused numerous breakthroughs in the field of testing, including conducting the first recorded oil ingestion engine kill test, introducing many new test techniques (such as the Government's first water-brake dynamometer system for survivability/vulnerability testing), and developing an effective three-phased building-block approach for performing controlled damage testing of engine compartment fires (and other types of tests with a limited number of target assets).

Furthermore, as an analyst, Walt helped to develop some of the standard damage and degraded-systems performance theories and predictive methodologies that are still used in most aircraft studies today. One of them—known as the Thompson Curve—is an algorithm for predicting foreign and domestic engine tolerance for fuel ingestion. He also was skilled at translating test data into vulnerability trends and then developing practical solutions for reducing these vulnerabilities. And he was adept at developing aircraft vulnerability inputs for computer-aided analysis programs as well as predicting the outcomes of dynamic interactions based on the results of static tests.

One thing Walt did not do as an analyst was lose touch with the range. "A lot of analysts can jockey the numbers," said Keithley, "but they never step foot on the range. That wasn't Walt. The range was where he always wanted to be." Thus, Walt's unique combination of analytical expertise and sense for practical application and testing made him an increasingly valued commodity by his coworkers and others in the community.

And as mentioned previously, his ability to share his expertise with others—in an unassuming way and with his typical dry sense of humor—was unsurpassed. He was an accomplished presenter and technical writer with more than 50 authored reports, many of which are considered landmark publications in the field today. They include vulnerability reports on the J57 and J79 turbojet and TF30 turbofan engines; combat damage assessment reports on Vietnam helicopter data; as well as multiple Joint Live Fire (JLF) reports on the T700 engine (including the Black Hawk and Apache variants), engine compartment fires, and foreign helicopter systems.

"He was an encyclopedia of vulnerability information," said Foulk, "with an uncanny ability to communicate it to others and apply it to other weapon systems, including ground vehicles and ships."

Walt also served on many national and international panels, boards, and committees, including numerous propulsion committees, the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS), and the Joint Live Fire Test Program (Aircraft Systems). He also was a member (and later a consultant) on multiple Source Selection Evaluation Boards (SSEB), including the 1500 HP Turbine Engine SSEB, the 800 SHP Advanced Technology Demonstrator SSEB, the 5000 SHP Modern Technology Demonstrator Engine SSEB, the Black Hawk Engine Follow-On SSEB, and the LHX Engine SSEB.

In addition to all of his work activities, Walt managed to find time for some interests outside of the office. Most notably, he restored vintage cars, including several 1950s Ford convertibles and an extremely rare 1957 Ford Thunderbird. In addition, he coached his sons' Little League baseball teams, was involved in model railroading, and built detailed model airplanes. "I got him involved in building model planes," said Polyak, "but the quality of his planes quickly surpassed mine." As evidence of his attention to detail, Walt was even known to "barber pole" the yellow stripes on the ejection handle of a 1/72-scale model plane. Clearly, the childhood artist in Walt never died.

A Continuing Legacy for Future Analysts

In 1997, Walt retired from Government service but not from his love for aviation or the field of survivability. He was hired

by his old friend Jim Foulk (who founded the SURVICE Engineering Company in 1981), and he continued to work on survivability projects as a contractor at ARL. These projects included the AIM-9X warhead damage assessment/lethality analyses, RPG helicopter damage assessment, AH-1S firing tests, Comanche LFT, CH-47F LFT, and PGU-28/B 20-mm evaluation. He also helped plan LFT programs for Apache engine fires, the Comanche T800 engine, MANPADS against turbofan engines, and several foreign threat systems.

"Right up until the end of his career," said Polyak, "I think Walt was as much in love with the business as he was in the beginning. He put 10 hours of effort into an 8-hour day." In addition, Polyak believes that Walt had an increasing sense of his legacy in the field. "It became important to him to try to transfer some of the information in his head to younger folks." Accordingly, he began giving training briefings to junior ARL and SURVICE analysts, highlighting some of the lessons and methods he had learned during his career. Also, the last report he authored was a landmark summary of his years studying the vulnerability reduction techniques in various threat helicopters.

To honor his many achievements—as well as his longstanding desire to ensure the country's survivability information was preserved for future analysts—SURVICE posthumously dedicated its technical library to Walt in June 2008. The Walter S. Thompson Memorial Library is now operated in coordination with the Aberdeen Satellite Office of the Survivability/Vulnerability Information Analysis Center (SURVIAC). Additionally, ARL is now in the process of constructing a full-scale, multi-position aircraft test fixture (or "tilt table") dedicated to the memory of its long-time employee. The fixture, which originated with a concept sketch that Walt drafted, will allow testers to generate more realistic shotlines to better determine aircraft vulnerability to ground fire. ■

JCAT Corner
Continued from page 6

analysis and provides training to Combat Aviation Brigades. As the OIF Theater OIC, CDR Burnette ensures assessors are properly trained and performing assessments according to JCAT standards.

1st LT Emilio Talipan, USAF, redeployed to CONUS in October 2008. One of his major contributions was identifying a new enemy tactic while he was conducting an assessment. This tactic is currently briefed to US Army units arriving in theatre. His weekly assessment briefs to the Aerial Maneuver Assessment Group (AMAG) were invaluable to the brigade staff, allowing for the continual adaption of friendly aviation tactics to meet the ever changing aerial battle-space. Lt Talipan's knowledge and experience regarding the capabilities of small arms and MANPADS were constantly used by the Brigade Intelligence community and Tactical Operations (TACOPS) officers to assist with assessing Surface to Air Fire (SAFIRE) events. Working out of Balad, he also provided data collection and threat awareness training to over 100 deployed aircrew, maintainers and intelligence personnel.

Arriving in Balad during the heat of August, representing the USAF, 1st LT Michael Belliss' primary focus was providing rapid response to aircraft damaged by SAFIRE and providing assessments of the damage and weapons systems used to the acquisition, test, survival, and operational communities. For JCAT to provide a greater opportunity to educate personnel in theater, Lt Belliss led the effort to update and re-align training and information briefings. He has led the assessment of 6 aircraft incidents and been recognized by the Corps Aviation Brigade Staff for rapidly responding to several incidents, including one catastrophic loss. Engineering expertise, coupled with his knowledge of threat weapons capabilities, has also enhanced the intelligence community's capability to assess numerous SAFIRE events. Currently, Lt Belliss is successfully spearheading the effort to increase JCAT awareness within US Air Force commands in theater.

CW03 David "Gunner" Mesa, USN, completed a very successful tour in Iraq and departed for home in December. Gunner distinguished himself as the first Navy Chief Warrant Officer to deploy as a JCAT assessor, serving at both Joint Base Balad and Al Asad Air Base. Throughout his tour, he focused on mentoring junior JCAT officers and assumed administrative duties for the entire team. Mr. Mesa led the way in responding to a request by the US Army Corps Aviation Brigade TACOPS Officers, providing newly arrived brigade staff with assessments on a bi-monthly basis. This allowed them to keep current threat trends in perspective and potentially re-evaluate US Army aviation tactics. His weapons expertise was also instrumental in the identification of previously undetermined munitions discovered in a cache. Gunner stayed very busy assessing 12 incidents, while also updating the database for 2007 and 2008 assessments in the Combat Damage Information Reporting System (CDIRS).

The newest member of the JCAT Forward team arrived in Al Asad in November 2008. LTJG Matt Kiefer, USN, spent several months on active duty working in support of the JCAT Forward Detachment from Wright-Patterson Air Force Base before deploying. There he assisted with both the CDIRS Quality Assurance process and system upgrades, as well as providing JCAT support to Naval operations in the Philippine Islands working an assessment. Matt prepared for his deployment over the last year by completing JCAT Phase I and II Assessor training, at Fort Rucker and Naval Air Warfare Center, Weapons Division, China Lake, respectively, and by attending the Threat Weapons and Effects Seminar at Hulbert Field. ■

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Calendar of Events

APR

Gun and Missile Systems Conference & Exhibition NDIA
6–9 April 2009
Kansas City, MO

AUSA's ILW Aviation Symposium & Exposition
6–9 April 2009
Arlington, VA

DEPS Directed Energy Systems Symposium
6–10 April 2009
Monterey, CA

Modeling & Simulation of Antennas
14–17 April 2009
Atlanta, GA

Armed Forces Communications & Electronics Assn.—West 2009
21–23 April 2009
Camp Lejeune, NC

Network Centric Warfare 2009
21–23 April 2009
Washington, DC

JCAT TWES
21–23 April 2009
Eglin AFB, FL

Infowar Con 2009
23–24 April 2009
Washington, DC

JASP Aircraft Survivability Short Course
28 April–1 May
Monterey, CA

MAY

AAAA Annual Convention
3–6 May 2009
Nashville, TN

Threat Modeling and Analysis Program (TMAP) Concepts & Capabilities Demonstration (CCD)
5–7 May 2009
Wright-Patterson AFB, OH

Test & Evaluation Using Modeling & Simulation
5–8 May 2009
Atlanta, GA

Joint Program Executive Office for Chemical and Biological Defense APBI
7–8 May 2009
Washington, DC

2009 Insensitive Munitions and Energetic Materials Technology Symposium
11–14 May 2009
Tucson, AZ

Joint Warfighting Conference and Exposition AFCEA
12–14 May 2009
Virginia Beach, VA

AHS Annual Forum
27–29 May 2009
Grapevine, TX

JUN

Test Week 2009
1–4 June 2009
Huntsville, AL

77th MORS Symposium
16–18 June 2009
Fort Leavenworth, KS

JASP Summer JMUM
23–25 June 2009
Colorado Springs, CO

NDIA Live Fire Test & Evaluation Conference
17–19 June 2009
Laurel, MD

JUL

JASP Summer PMSG
14–16 July 2009
Key West, FL

AUG

45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
2–5 August 2009
Denver, CO

Information for inclusion in the Calendar of Events may be sent to:

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